Global
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Intergovernmental Oceanographic Commission

Strategic Design Plan for the IOC-WMO-UNEP-ICSU-FAO Living Marine Resources Panel of the Global Ocean Observing System (GOOS)

Tracking Change in Marine Ecosystems

GOOS Report No. 94
IOC/INF-1150

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Abstract
This report constitutes the Strategic Design Plan for the Living Marine Resources Module of GOOS. The Strategic Design Plan is based on the conclusions and recommendations of the GOOS Living Marine Resources Panel, which held four meetings between 1998-2000. The Strategic Design Plan recommends a broad, ecosystem-based approach to the assessment and monitoring of living marine resources, with an emphasis on understanding change in marine ecosystems over time. Because marine ecosystems are highly diverse, no single global-level set of observations is recommended. The Strategic Design Plan specifies the elements which should be considered in the development of open ocean and near shore observing systems, but specific details are left to local experts. Regional Analysis Centres are recommended a means to bring together ecosystem information for analysis and for the development of useful information products.

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EXECUTIVE SUMMARY

The sustainability of the oceans' living marine resources (LMR) is threatened by a wide variety of factors. Overfishing, habitat disturbance and loss, pollution and the potential effect of a changing climate all combine to reduce the health of the world's oceans. Key to addressing these issues is better information regarding the status of the world's LMRs, and the factors driving change. With this in mind, the goal of LMR-GOOS has been to:

"provide operationally useful information on changes in the state of living marine resources and ecosystems. The objectives are to obtain from various sources relevant oceanographic and climatic data, along with biological, fisheries and other information on the marine ecosystems, to compile and analyze these data, to describe the varying state of the ecosystems, and to predict future states of the ecosystems, including exploited species, on useful time scales. A consequence of these efforts should be the identification and development of the more powerful and cost-effective means for monitoring marine ecosystems required to meet the LMR-GOOS goal."

In achieving this goal the LMR-GOOS monitoring program should attempt to provide information that:

(i) describes changes in ecosystems over time, including fluctuations in abundance and spatial distribution of species;
(ii) helps interpret the observed changes in relation to such factors as natural environmental variability, anthropogenic climate change (including increased ultraviolet radiation), predation/disease, and fishing activities; and,
(iii) contributes to forecasting of future states of marine ecosystems.

To address these needs, LMR-GOOS developed a broad, ecosystem-based approach. Recognizing the increasing heterogeneity of marine ecosystems as one moves from the open ocean toward shore, the approach is structured according to three systems – open ocean, coastal ocean and inshore. Open ocean observations are necessarily minimalist, relying on ships of opportunity, remote sensing and fishing industry statistics. The inshore system was not addressed by LMR-GOOS due to its heterogeneity and complexity and the lack of specialists in inshore studies on the panel.

Because of its productive capacity and proximity to anthropogenic influences, the coastal ocean is a primary focus of LMR-GOOS. Unlike observing systems for climate, marine pollution and ocean service, there is no 'one-size-fits-all' observing system that is equally valid or useful for all coastal marine ecosystems under consideration. Coastal ocean ecosystems, and the processes, which drive them, are simply too variable and the design of specific observing plans must be based on the knowledge of local scientists. Four examples of regional LMR observing systems – Scotian Shelf, Gulf of Guinea, Yellow Sea/East China Sea and coastal upwelling systems - are presented as examples, as design principles for regional LMR-GOOS programs. These are intended to be adapted and customized by local experts elsewhere.

Data and information management, and the process of transforming data into useful products, comprise an essential element of the LMR-GOOS approach. LMR data products, such as forecasts of ecosystem states, are logically produced on an ecosystem scale, which typically

involves large ocean areas. Regional Analysis Centers (RACs), which would serve to compile data and information on appropriate ecosystem scales, and to generate appropriate forecasts and other data products, should be the fundamental unit on which LMR-GOOS is developed. Existing regional marine science organizations such as ICES or PICES could host RACs as could existing regional ecosystem observing programs.

A key linkage between the observing program and useful predictions of system dynamics is process studies and modeling. Programs such as GLOBEC will provide critical information on physical-chemical-biological processes, develop advanced observing technologies, and identify crucial variables and locations for long time series analyses of climate variability and marine ecosystem response. In turn, LMR-GOOS will provide time series data for research programs.

The first steps toward implementation of a global LMR-GOOS must be the integration of existing observing systems into a more consistent, ecosystem-based approach utilizing the regional design principles, and a significant increase in capacity to enable full participation throughout the developing world. In many areas, ongoing observing programs such as those identified as LMR components of the GOOS Initial Observing System comprise significant components of a regional system which need only minor augmentation and linkage through a RAC. In other areas, not even rudimentary monitoring capacities exist. The challenge now is to identify existing programs and gaps, and to find resources to develop the program on a global scale.

SUMMARY OF KEY RECOMMENDATIONS

These recommendations are aimed toward the national and international agencies that have ultimate responsibility for the implementation of LMR-GOOS.

- Adopt a broad, ecosystem-based approach to living marine resources assessment and monitoring. Recognize that all marine ecosystems are unique, that no uniform global-level observing system will be valid, and that observing systems must be tailored to specific local conditions and requirements.

- Develop monitoring systems at three biogeographical scales - open ocean (basin or sub-basin scale), coastal ocean (large marine ecosystem scale) and inshore (embayment or estuary-scale) – with increasing system complexity from open ocean to inshore. A design strategy and examples for open ocean and regional observing systems are provided here.

- Establish Regional Analysis Centers (RACs) for each major ecosystem. RACs will manage, analyze and synthesize ecosystem data from monitoring and assessment programs, and produce the specific products for end-users. Capacity building will be facilitated as scientists from countries at different stages of development work together to make observations and interpret them in ways consumers will find useful.

- Utilize fully existing and developing observing technologies for cost effective, synoptic sampling, e.g., remote sensing (ocean color, wind fields, sea surface height, temperature and salinity), instrumented continuous plankton recorders and optical plankton recorders.

- Strengthen linkages with national and international research and observing programs that may contribute to LMR-GOOS, most notably GLOBEC and Census of Marine Life.

1. INTRODUCTION

The Global Ocean Observing System (GOOS) is intended to provide systematic information about the status of the global ocean to benefit a broad range of users. Primary among these are the managers, producers and consumers of the world's living marine resources. According to the *GOOS Prospectus 1998, "those concerned with the harvest and conservation of living marine resources need operationally useful information on changes in the state of those resources and the ecosystems in which they exist, for example to be able to assess present stocks and predict their future states, and their vulnerability to forcing by changes in climate, fishing pressure, pollution, or the incidence of harmful algal blooms."* Billions of individuals worldwide rely on the ocean's living marine resources for food, employment, recreation and aesthetics. The sustainable management of marine ecosystems to provide these benefits is an increasingly complex task, and one that will require increasingly sophisticated observing systems.

The term "living marine resources" can be used to denote not only those organisms that are harvested, but also those with which they interact and, more generally, the biotic components of marine ecosystems. These organisms are important not only as sources of food and other raw materials, thus as elements of national economies, but also as essential components of the natural systems that support human life on the planet. Therefore, it is as necessary to keep track of changes in the living marine resources and the ecosystems that they occupy as it is to keep track of changes in the human activity and marine environment whereby they are forced.

These considerations suggest that monitoring programs of GOOS should include a substantial component devoted to the living marine resources. Accordingly the Living Marine Resource panel was established and in two years of discussions has identified some general principles to be taken into account in LMR monitoring. These principles are discussed in the report that follows. The Panel did not attempt to design actual regional monitoring programs where local expertise is necessary to ensure that local ecosystem characteristics have been taken fully into account.

2. CONCEPTUAL APPROACH

Living marine resources are widely distributed throughout the world ocean, from the coastal fringe to the high seas. Harvestable resources consist of plants, mainly in nearshore waters, and animals at several trophic levels, both at or near the sea surface, at mid-depths, and on the sea floor of the continental shelf. While lower trophic levels, from phytoplankton up to forage animals, both invertebrate and vertebrate, are not generally harvested, their production is the vital support base for those resources that are. Thus in principle, to monitor the present state and changes in harvestable living marine resources would require monitoring the living components of entire marine ecosystems.

Moreover, the functioning of marine ecosystems is affected by circulation and mixing in the physical environment, so the LMR monitoring system must also include the important physical variables. However, monitoring of such variables is well advanced and ongoing, so the LMR design plan will assume its existence but will not provide for it in detail.

The goal of LMR-GOOS is to provide operationally useful information on changes in marine ecosystems and their living marine resources. The principal users of the output of an LMR monitoring system will be those concerned with the harvest management, and sustainable use of living marine resources. Therefore one central focus of the LMR-GOOS module must be commercial fisheries.

However, in some regions, the importance of fisheries may be outweighed by exploitation of other ecosystem services (e.g., offshore oil and gas production, or tourism). Also, national policies and international conventions on biodiversity and ecosystem protection require consideration. These considerations have changed, and will further change, the nature of fishery management. Thus the LMR observation program must go beyond the monitoring of a few target species to allow assessments of the state of living marine resources in a broad ecosystem context.

New methods for monitoring marine biota are being developed and promise more comprehensive and cost-effective sampling that will provide much greater insight into the nature and causes of ecosystem change (see for example the Census of Marine Life papers in *Oceanography*, vol. 12 (3), 1999). While recognizing the potential of these methods, the LMR Panel elected to focus its present attention on monitoring systems using technology that is now widely available. As new methods come on line and prove reliable, they can be substituted for those discussed here.

Considerations of scale

While a common observation scheme is likely to be applicable in the open ocean, the diversity of coastal ecosystems will require different approaches appropriate to the specific characteristics of regions. Both the sampling frequency in space and time and the biological targets of sampling will differ, for example, between coastal upwelling ecosystems, western boundary currents systems, open seas, and semi-enclosed seas with high river input and human impacts. Design of the overall LMR monitoring system should seek to identify types of systems within which generalizations about selected kinds of necessary measurements can be made.

Changes in marine ecosystems are forced externally by the variable physical environment and by human activities. Fishing has important effects, but other activities, such as oil, gas, and mineral production, pollution from coastal sources, and tourism are of increasing importance. Interactions within ecosystems also cause changes in individual components, for example through predator-prey interactions. If useful products are to be made available, such as now-casts or forecasts of the distribution and abundance of a desired component or of changes in ecosystem states, all of the necessary ingredients, or at least proxies for them, must be monitored. In addition, these ingredients must be incorporated in appropriate ecosystem models to produce the desired products.

Monitoring of marine biota is not well advanced, especially on the large scale. It is mainly carried out on a regional basis in connection with fishery investigations. The only basin scale biological monitoring regularly carried out is the satellite measurement of ocean color which is a measure of phytoplankton standing stock and, under special circumstances, can be used for estimating primary production. In principle, the lower trophic levels could be monitored with towed devices (e.g., the Continuous Plankton Sampler) or flow-through devices. However, apart from a few CPR transects, largely in the North Atlantic, funds for such sampling programs have been limited.

The principal harvested resources, finfish and shellfish, are sampled primarily by the fisheries and to a lesser extent by fishery-independent surveys, and this sampling is usually on a sub-regional scale. While it is not difficult to generalize the larger scale sampling requirements and to propose methodological standards, funding for large scale biotic monitoring is at present not in sight.

The constraints reflected above are inherent in the strategic plan that follows.

The role of research

Apart from the technological challenges of adequately sampling the components of marine ecosystems relevant to LMR-GOOS, there is also a major challenge in transforming the observations into products of value to users. These might include forecasts of the location and abundance of desired species, ecosystem changes, and the consequences of different patterns of harvest. Such forecasts will depend on establishing the links between cause and effect in ecosystem models. There are relatively few such models in operational use, though this is an active area of research. The modeling activities of GLOBEC will be of particular relevance to this problem. A principal value of such research, in relation to LMR-GOOS, will be the development and testing of such models, in association with new sampling and observational technologies.

Research through GLOBEC will contribute to identifying the crucial variables and locations for long time series analyses of climate variability and marine ecosystem responses. This should lead to the co-ordinated network of sampling activities to assess ecosystem structure and changes that LMR-GOOS will require.

The results of GLOBEC research are needed to transform the outputs of the LMR monitoring system into useful products. For example, such research will help to establish how measures of ecosystem change such as variations in zooplankton abundance can be linked in an explanatory and predictive way to changes in the distribution and abundance of fish stocks. To facilitate this, the global monitoring system should aim to measure ecosystem variables that are useful to GLOBEC research, and should take full advantage of new and emerging technologies.

Further information on the potential contribution of GLOBEC research to the development of LMR monitoring is given in Annex V.

3. DESIGN PRINCIPLES FOR GOOS-LMR MONITORING SYSTEMS

Three-system approach

Monitoring systems for the open ocean, the coastal ocean, and inshore will differ significantly in the frequency of observations in time and space and to some extent in the variables observed. These differences will reflect the nature of the time and space gradients of these properties as well as the uses to which the data will be put. In order to obtain a useful description of the variability, sampling frequency will normally increase in passing from the open ocean to the inshore. While the physical variables of interest will be much the same offshore and inshore, the numbers and types of necessary biological observations will also increase towards inshore.

The demand for products, and hence the funding, of monitoring systems, can also be expected to be greatest inshore. Therefore, it seems appropriate to speak in general terms of three nested monitoring systems. The open ocean system extends shoreward to where presence of the coastal boundary is felt, generally to the edge of the continental shelf. The coastal ocean system then extends from there to the inshore system where terrestrial influences tend to dominate. These boundaries fall roughly at about 200 miles and about three miles from the land-sea boundary.

Note that continuity in space between observations can be provided in two dimensions by remote sensing and in one dimension by underway recording or by towed devices. At fixed locations, continuity in time can be provided by recording devices.

In all monitoring systems for LMR purposes, there is a need for information on the atmospheric forcing, ocean velocity field, and distributions of temperature and salinity at the surface and upper mixed layer. Such information is also required for monitoring of ocean climate and health of the ocean. In addition, biological studies also utilize information on the distributions of dissolved oxygen and of nutrient substances such as inorganic compounds of nitrogen, phosphorus, silicon, and iron. For assessment of living marine resources, a case might be made for quantitative sampling at all trophic levels from bacteria to whales. The problem is to select from these possibilities the most diagnostic and cost-effective suite of observations that will yield information of direct value to users of living marine resources.

Design Considerations

The outline for a regional observing system should include the following elements:

- *Objectives*: Generally, the objective of LMR-GOOS will be to provide operationally useful information on the state of living marine resources and their ecosystems. Such information should include changes in physical conditions and ecosystem components required for now-casting and eventual forecasting of the ecosystem and of its living resources. Specifically, each observation system must consider local objectives, e.g., support of management, support of fishing and other operational activities, support of scientific activities, protection of the environment.

- *Users*: Those requiring knowledge of ecosystem changes for research purposes and for management of human activities affecting ecosystems and their components, especially those concerned with the harvest of fish and shellfish and the sustainability of that harvest.
- *Characteristics*: Plans should be practicable, cost-effective, and within the capabilities of those concerned with living marine resources in the region. Minimal initial monitoring plans should use existing observational programs and methods to the extent possible.
- *System analysis of key ecosystem processes and features*: Describe physical features, dominant biological processes, and observed variability in physical and biological characteristics on interannual and interdecadal time scales.
- *Monitoring requirements*: Identify ecosystem components and conditions that should be monitored for LMR purposes, together with priorities for elements to be observed and desired sampling frequencies appropriate for the region. This should include a consideration of available and potential measurement tools and opportunities. Table 1 contains a listing of possible components and conditions for monitoring, while generic descriptions of each are given in Annex 1. (*Note: while the Table 1 and Annex I provides a useful framework for these considerations, local experts must provide the details such as priorities and desired sampling frequencies specific to the region).*
- *Products*: Describe how the required monitoring information will be used to develop products for the identified users, and what those products will be. This should include identification of appropriate diagnostic, simulation, and data assimilation models.

4. RECOMMENDED OBSERVING SYSTEMS

4.1 INSHORE SYSTEM

In view of the heterogeneity and complexity of inshore systems and the lack of specialists in inshore studies on the panel, designs of representative inshore systems were not attempted. This matter should be given early attention by a task group of appropriate specialists.

4.2 COASTAL OCEAN SYSTEM

The heterogeneity of coastal ocean ecosystems precludes a “one-size-fits-all” approach to the development of an observing system. No single set of observations, scales, analysis techniques or data products will be equally valid in all systems. However, general observations can be identified that will be essential, if not sufficient, to characterize change in all systems. With this in mind the panel developed a generic set of ecosystem observations and products to guide development of specific coastal observing systems, as well as four specific examples to illustrate the approach.

An example has been developed for small pelagic fish in the South-Central region of Chile, along with a list of possible regional models and products and the capacity building required for such an activity in that region (see GOOS Report. No. 74, Annex V, 1999).

The generic table of regional observations (Table 1*) lists the minimum observations that could define a comprehensive ecosystem observing program. There was no attempt to identify explicitly how the selected observations can be parameterized and linked to specific products through models. This also must be left to local experts.

The panel also developed a table of generic monitoring products (Section 5.2), which would apply to the regional as well as open ocean observing system. These should be defined in relation to performance measures for the ecosystem objectives of ocean use management plans for the region in question. The table lists commonly monitored parameters, such as population level, fishing activity, and community structure and identifies useful indices related to these and how the indices can be utilized operationally. Such a table can be used to determine which monitored parameters can actually contribute to operational products, a primary objective of GOOS.

Examples of regional observing systems (see Annex II, 2.2-2.5) include generic coastal upwelling systems, the Scotian Shelf, the Yellow Sea/East China Sea and the Gulf of Guinea. Each contains broad ecosystem observations on biological resources, physical and chemical oceanography and atmospheric forcing.

Table 1. Possible Regional Observations

***NOTE: This table is provided only as a framework. For use in any given region, information on priorities, desired sampling frequencies and other details must be provided by those familiar with the region.**

Major ecological group or condition	Subgroup or observation	Observation or parameter of interest
Target Species of fishing	Fishing industry	Catch by area and species
Target Species of fishing.	Fishing industry	Length frequency samples of landings by species and area.
Target Species of fishing.	Fishing industry	Length/weight relationships for key species
Target species of fishing.	Fishing industry	Effort
Top Predator	Whales, dolphins, porpoises, seals, etc.	Abundance
Top Predator	Whales, dolphins, porpoises, seals, etc.	Food habits e.g., stomach contents, for key predators
Top Predator	Sharks	By-catch/abundance
Top Predator	Sea birds	Abundance, fledging success and breeding success
Commercially exploited finfish and forage species	Surveys, e.g. trawl	Catch by area and species

Major ecological group or condition	**Subgroup or observation**	**Observation or parameter of interest**
Commercially exploited finfish and forage species	Acoustic surveys	Abundance by area and species
Commercially exploited finfish and forage species	Fish eggs/larvae	Abundance by area and species
Zooplankton	Continuous plankton transects (e.g. CPR)	Abundance and species by horizontal transect
Phytoplankton	Water sampling	Column-integrated species and abundance using discrete depth samples
Phytoplankton	Ocean color	Satellite-spectral (visible)
Benthos	Non-commercial species	Community structure, appropriate methodology
Habitat	Inshore habitats essential for fish production	Areal extent
Chemistry	Nutrients/oxygen	Discrete depths and column integrated
Hydrography	Temperature/salinity	CTD profiles
Hydrography	Temperature/salinity	CTD profiles
Hydrography	Ocean pigments	Satellite-spectral
Hydrography	Ocean winds	Satellite-spectral
Hydrography	Sea height (altimetry)	Satellite-spectral
Hydrography	Temperature	Satellite-spectral
Atmospheric forcing	Wind fields	Wind-stress
Atmospheric forcing	Upwelling indices	a. alongshore wind stress; b. offshore SST gradient
Composite indices	Pressure pattern indices (SOE, PNA, NAO, etc.)	Selected permanent weather stations
Composite indices	Coastal sea level	Permanent coastal tide gauges

4.3 OPEN OCEAN SYSTEM

Open ocean systems are less heterogeneous than coastal systems, and thus more amenable to a standardized approach. In general terms, monitoring of this system could be as follows. An ocean basin would be overflown by satellites measuring sea surface height, winds, temperature, and ocean color. Surface weather would be reported by voluntary observing ships reporting to the World Meteorological Organization (WMO) network. On transects selected to cross major features of circulation or of changes in properties (e.g., ocean fronts), selected merchant and research ships would tow plankton recorders and drop expendable bathythermographs (XBTs) at appropriate intervals (e.g., hourly). Implementation of the Array for Real-time Geostrophic Oceanography (Argo) program will add valuable information on temperature and currents in the upper ocean. In a minimal system, other ecosystem components and conditions would be observed as follows:

Top predators: irregular, reported by observers on fishing and research vessels
Commercial finfish: irregular, reported by fishing and research vessels
Pelagic forage: irregular, reported by fishing and research vessels
Benthos: not observed
Zooplankton: irregular, reported by research vessels
Phytoplankton: irregular, reported by research vessels
Nutrient Chemistry: irregular, reported by research vessels
Salinity, dissolved oxygen: irregular, reported by research vessels.

A composite picture at quarterly intervals could be built on the framework provided by the satellite data and transect observations, with the irregular data inserted where applicable. This analysis, which would provide the basis for elaboration of useful products, would be made at appropriate basin-scale regional analysis centers.

Further development of open ocean observing systems is discussed in Annex II, 2.1.

5. CROSS-CUTTING ELEMENTS TO BE CONSIDERED IN THE DEVELOPMENT OF OPEN OCEAN, COASTAL OCEAN AND INSHORE PLANTS

5.1 DATA AND INFORMATION MANAGEMENT – REGIONAL ANALYSIS CENTERS

The problem of data and information management is general for GOOS, and the LMR component can not be dealt with independently. However, the special characteristics of LMR data must be taken into account as the data management plan is developed. There is long experience in handling physical atmospheric and oceanographic data, which benefits from the existing observation networks and general agreement on data specification and standards. Biological data are far more heterogeneous, and widespread standardization of methods has only been achieved in a few cases, such as the fishery statistics compiled by FAO. There is no general agreement on methods and standards, so the archiving of biological data requires comprehensive information characterizing the data.

The treatment of data resulting from the LMR components of GOOS will require bringing them together with relevant physical and other data in a holistic analysis of the ecosystem of interest. Such analyses are essential elements of monitoring systems. A mechanism for carrying them out could be regional analysis centers (RACs), where scientists of appropriate disciplines from participating countries would undertake the work. Work in these centers could also serve a central role in capacity building.

Such analysis centers would receive climate, oceanographic, and fisheries data from national and international sources and on a regular basis would prepare descriptions of the current state of the ecosystem and recent and longer term changes therein, including climate forcing, ocean physical conditions and circulation, and abundance and distribution of various biological components of the system. To the extent that available data and understanding of the system permitted, forecasts would be made of probable future conditions of these same ecosystem components. The products of the now-casting and forecasting analyses would be regularly provided to participating countries and organizations and would be made widely available on the web. Results of the analyses would also be used for improving the observational system.

As a first step in the development of regional analysis centers, it has been proposed that programs and organizations such as the International Council for the Exploration of the Sea (ICES), the Helsinki Commission (HELCOM), the North Pacific Marine Science Organization (PICES), and the Benguela Current Large Marine Ecosystem (BCLME) program initiate discussions of the design and possible implementation of such centers in their regions of interest. These discussions should include assessment of present exchange arrangements for climate, oceanographic, and fisheries data relating to those regions.

5.2 RAC PRODUCTS AND BENEFITS

Because of the heterogeneity of marine ecosystems, and the different needs of users worldwide, there is not a single set of products that would be generated. Each RAC will develop a suite of products, and methods to deliver products to users, based on regional biological and physical conditions and on capacities for data analysis, interpretation and dissemination. Table 2 shows examples of data products (indices) that might be produced by the RACs using monitored parameters, and possible utilizations of the products.

Table 2. Possible LMR-GOOS data products

Observation of interest	Monitored parameters	Indices	UTILIZATION
TOP PREDATORS, COMMERCIAL FINFISH, SMALL PELAGIC FISH, FORAGE FISH			
Population status	Spawner stock biomass	Percent relative to pristine	Operational management
Population status	Recruits	Relative to median	Operational management
Population status	Growth	Relative to median	Operational management
Fishing activity	Catch rates	Median tendency	Population estimate
Fishing activity	Fleet behavior	Effort/Area/Duration	Modify catchability coefficient

Observation of interest	Monitored parameters	Indices	UTILIZATION
Fishing activity	Bycatch/Incidental Mortality (target and non-commercial species)	Percent target Species	Conservation/fishing practice
Community structure	Biodiversity	Richness, evenness	Detection of ecosystem change
Community structure	Biomass/Abundance Ratio	Dominance	Detection of regime shift
PELAGIC ENVIRONMENT			
Zooplankton	Biomass/Abundance	Means/Trends	Detection of ecosystem change
Zooplankton	Biodiversity	Richness, Evenness	Detection of ecosystem change
Zooplankton	Diet	Percent change, composition	Inputs to Multi-species Models
Phytoplankton	Biodiversity	Richness, Evenness	Detection of ecosystem change
Phytoplankton	Length spectrum	Slope	Detection of ecosystem change
ENVIRONMENTAL PARAMETERS			
Biological oceanography (remote sensing)	Ocean color	Phytoplankton biomass, primary productivity, turbidity	Large ecosystem changes
Physical oceanography (remote sensing)	Sea height	Mesoscale eddies	Pelagic habitat
Physical oceanography (*in situ*)	Temperature (vertical, horizontal)	Means, deviations, trends, proportion of area, stratification, gradients	Upwelling activity, frontal activity
Physical oceanography (*in situ*)	Dissolved oxygen	Proportion of shelf/water column	Pelagic habitat

Observation of interest	Monitored parameters	Indices	UTILIZATION
		above/below threshold	
Physical oceanography (*in situ*)	Atmospheric pressure	Gradients, alongshore and cross shore	Wind stress, upwelling strength

Where appropriate, products of the monitoring, analysis and interpretation could be disseminated effectively through a well-designed web site hosted by a RAC. A RAC's web-based products would contain a hierarchy of information detail. At the most general level, 'red-flag alerts' of changing ecosystem conditions, status of stock reports, and maps of relevant ocean features would be available for decision-makers and those concerned with the general condition of the ocean. A second level would include the types of information products shown above, which would typically be useful for resource scientists and managers. These might include stability and wind mixing indices, bycatch/incidental mortality estimates, length and age structures, and community structure. At a third, most detailed level, resource scientists and researchers would have access to raw formatted data, available through links to institutions responsible for the observations.

Application of the identified products should lead to various benefits for the identified user groups. These might include:

1. Maintaining the value of ecosystem goods and services, including maintaining the ability of the systems to respond within historical dynamic limits.
2. Improving risk assessment of capital investments.
3. Improving understanding of the mechanisms of integrated production processes in coastal and oceanic systems.
4. Improving prediction of changes in the dominance of important species such as those that result from regime shifts.
5. Detecting and minimizing wasteful and harmful practices.
6. Improving communication among research, monitoring and operational activities.
7. Improving appreciation of the regional and global implications of local activities in the marine environment.
8. Helping coastal states meet their commitments to international agreements, such as Agenda 21, Convention on Biological Diversity, Code of Conduct on Responsible Fishing, and the Convention on Straddling Stocks.

The provision of these benefits depends on the initiation and sustaining of a system for routine observations, data analysis, and provision of data and information products that are relevant to user groups. Unlike other elements of GOOS that primarily address physical and chemical characteristics of the ocean, LMR-GOOS must be implemented on an ecosystem (or basin-scale as appropriate) basis. Therefore, LMR-GOOS data products will best be generated not at the national or local, but a regional level.

5.3 CRITICAL HABITAT

A key element in achieving sustainable fisheries is the identification, conservation, and restoration of fish habitat. Healthy habitat is a basic requirement for the reproduction, growth, migration, and livelihood of sustainable fishery stocks. Essential Fish Habitat (EFH) may be defined as those waters and substrate necessary for spawning, feeding or growth to maturity and includes the associated physical, chemical, and biological properties that are used by fish and are necessary to support a managed level of fish biomass production.

The management of commercial fishery resources has historically focused on single species and concentrated on assessing stock size and controlling fishing mortality. However, the EFH concept is based on an ecosystem approach to comprehensive fisheries management and includes the conservation and management of fish habitat as important elements. For most species, present knowledge is poor about what habitat must be included in identifying EFH. Accurately delineating the habitat requirements of a fish species, or a particular life stage, will require detailed and comprehensive assessment of where these animals live along with the associated marine environmental conditions.

Sizeable proportions of commercial coastal pelagic and demersal fish stocks are dependent at some stage of their lives on estuaries in addition to coastal waters. For example, estuarine wetland areas are EFH for many fish species that live and spawn in coastal waters and have young that migrate into estuarine nursery grounds where they grow into subadults. The habitat characteristics for demersal fish species in coastal and open ocean waters often include bottom structure, hydrodynamics and general hydrology. The EFH for pelagic species in both the coastal and open ocean waters is often linked to dynamic oceanographic characteristics, features, processes, and water column structure. In tropical areas, coral reefs and related environments form EFH for many fishery resources. Anadromous fish species, such as salmon, have habitat requirements in marine waters as well as in freshwaters.

A key element in considering EFH is the identification of existing and potential threats to habitat and the conservation and enhancement measures necessary to eliminate or minimize these threats. The nature and extent of particular threats will vary by region and usually depend on habitat type, exposure, and other environmental variables. Habitat degradation, e.g., destruction of wetlands, eutrophication, harmful algal blooms, and direct degradation or alteration of the environment, is a critical threat to EFH.

5.4 CAPACITY BUILDING

To implement LMR-GOOS, basic and specialised skills are required as well as experience and infrastructure. There is therefore, the need to match the necessary infrastructure with the appropriate skills. The areas for training that would produce the essential skills for LMR-GOOS are as follows:

- Hydroacoustic techniques (for fish and plankton surveys)
- Trawl surveys and benthic surveys
- Capabilities in image processing and applications of satellite remote sensing to oceanography and fisheries

- Expanded GIS capabilities
- Database management and information sharing
- Numerical expertise in fisheries science
- Ecosystem-based modeling skills
- Multidisciplinary training for fisheries managers especially in ecosystem and biodiversity management, seabed mining, law of the sea, etc.
- Integrated coastal area management
- Genetic methods and application
- General training of oceanographic technicians
- Training of fisheries inspectors and observers
- Environmental monitoring
- Language education

The necessary infrastructure would span the complete spectrum from basic tools to utilization of Internet facilities and would include:

- Computers and relevant software
- Internet connection
- Internal and external communication
- Equipment and sampling gear for in-situ measurements and processing
- Laboratory equipment

6. BUILDING AND TESTING THE SYSTEM

Monitoring systems within GOOS will in most cases evolve from existing observational programs. Some programs can be identified as elements of the GOOS Initial Observing Systems while others can contribute to development of the global system as pilot projects.

Numerous systems exist globally which are consistent with GOOS principles and which collect information required by LMR-GOOS. At the request of the panel, IOC is compiling and will make available information on significant monitoring and assessment programs of its member states.

Several such monitoring programs have been identified by the panel and proposed for incorporation in the IOS; these are elaborated in Annex III. Each of these programs regularly makes observations and releases data relevant to LMR needs. Depending on future development of the IOS, other appropriate monitoring programs can be added as they are identified.

The panel has also selected several ongoing or proposed programs that serve to develop or test approaches to LMR monitoring that might be incorporated in the eventual global system. Accordingly, their findings can be expected to contribute to the design of that system. There are undoubtedly other such programs elsewhere in the world that would be equally appropriate pilot projects, and the selected programs should be considered only as examples. These are described in Annex IV.

ANNEX I

LMR-GOOS OBSERVING SYSTEM ELEMENTS

I. Elaboration of Ecosystem Components

A: Top predators and other large species (seabirds, marine mammals, sharks and turtles).

While large species and top predators have in the past formed the basis of industries, their economic importance is now more limited. However, the health of their populations is of evident human concern both for economic and esthetic reasons and also because their position at the apex of the food chain makes them integrators of contamination and thus valuable indicators of ecosystem health. Other large species such as manatees, while not predators, are also included in this section because the information requirements are essentially similar to those required for the top predators.

(i) Abundance and distribution of these species are essential information. Since seabirds and marine mammals are air breathers, surveys based upon sightings are possible. These sighting surveys might be line transect surveys in the case of cetacea, haul-out site identification and counts in the case of pinnipeds, and breeding colony identification and counts in the case of seabirds. Seabird distributions may also be estimated by at sea observer programs on ships of opportunity. Surveying the abundance of the larger sharks is difficult. One approach is to use by-catch data from commercial fisheries.

(ii) Reproduction. Studies of reproductive capacity are important, particularly where concerns exist that human activities may affect it. Examples of possible impacts might be the effects of contaminants on reproductive ability, such as caused by endocrine disrupters (Report of the Fourth Session of HOTO Panel, Singapore, October 1997), or the effect of fishing on forage species near breeding sites, which may influence chick or pup survival.

(iii) Ecosystem role. Top predators particularly at historic population levels generate significant predation mortality on lower trophic levels. They might perhaps also act as keystone species and serve to structure ecosystems. A further ecosystem concern is that abundance of top predators, e.g. the size of pinnipeds, can be sensitive to availability of prey.

(iv) Causes of mortality. Of particular concern are direct mortality rates induced by human activities such as hunting, incidental by-catch (particularly of cetaceans), boat collisions, etc. These are best determined by monitoring body counts. Other monitoring might include recording sites and counts of the strandings of marine mammals and wrecks of seabirds and of starvation-induced deaths. Tagging studies can illuminate migration and mortality processes. Photo identification can provide a powerful equivalent to tagging studies for marine mammals. These and tagging studies, including large smart tags, may elucidate abundance, migration and mortality questions.

B: Commercial finfish (pelagic and demersal)

Commercial finfish (fish used for human consumption) are of obvious economic importance and provide the resource underpinning of fisheries throughout the world. The common property nature of fisheries means that Governments are typically involved in their management, and that management in accord with the precautionary approach should be based upon an appropriate level of knowledge (see for example FAO 1995, Fish Tech. paper 350 pt. 1). This requires routine monitoring of each significant fish stock. Desired information is:

(i) Abundance and distribution. A knowledge of the stock abundance, often by size, relative to target and limit reference points for its biomass is an obvious need. Abundance is ideally measured in absolute terms and ideally also characterized by size or age. Techniques for obtaining this information include sequential population analysis or depletion models based upon commercial catch data, fish aging data and commercial or research estimates of abundance trends. For some demersal species, bottom trawl surveys are frequently employed to estimate abundance; while for some pelagic or semi-pelagic species, acoustic estimation of abundance is an alternative or additional source of abundance information. Other estimators of abundance include egg surveys coupled with estimates of average adult fecundity and visual sighting surveys. Where absolute estimates of abundance are not feasible or where economic constraints prohibit the expensive sampling required for these methods, measures of relative abundance may be used. Examples of relative abundance indices are commercial catch per unit effort data by gear type and research vessel trawl survey catch rates. Where fishing effort is not available, total commercial catch may give an indication of biomass, but one that is confounded with changes in exploitation level. The spatial distribution of fish stocks can also be of management significance in addition to the estimates of overall abundance. Stocks may become more or less widely distributed in different environmental conditions and this can influence how they are assessed and how they should be managed. It may also influence the jurisdiction of stocks if they change their distribution from the EEZ of one state to that of another or to the open ocean. Distribution may be measured by commercial catch data, commercial catch per unit effort data, research fishing surveys (particularly with trawls) and research vessel (or chartered commercial vessel) and acoustic surveys. Size distribution (size spectra) of all commercial fish may also prove a valuable management tool. Sampling for size spectra often results from aggregation of results from species-specific surveys.

(ii) Reproduction. Failures of fish stocks are most often thought to be failures of reproduction, either due to removal of spawning biomass by excessive fishing or to changing environmental circumstances affecting either adult biomass and fecundity or larval survival. Monitoring reproduction is a means of obtaining early warnings of problems and an understanding of the processes underlying the ability of the fish stock to reproduce itself in the face of fishing pressure. Techniques for monitoring include the interpretation of the abundance estimation approaches described in (i) above plus studies of fish fecundity and of egg and larval survival processes.

(iii) Ecosystem role. Species in this group may have multiple roles in the ecosystem as predators, as prey and possibly as scavengers. The state of the marine ecosystem may influence individual fish stocks, and the way individual fish stocks are harvested may influence components of the marine ecosystem. Fish stocks may be influenced by the abundance of predator and prey species and by parasites and their secondary hosts. Appropriate monitoring may include the collection of stomach content data, condition factor, gonadal/somatic indices, indices of liver weight, etc. Abundance indices of important non-commercial species may also be indicated if these are significant predators or prey. Part of this and other monitoring will include the development of suitable mathematical modeling tools to convert data on what can be observed into estimates of the information that is needed. As a concommitant to fishing, commercial fishing may affect other marine biota by directly killing, by providing food in the form of discarded catch, offal and the products of non-catch mortality, by the effects of trade specific litter (particularly lost or discarded gear which may cause entanglement or ghost fishing), and by disturbing substrates. It may also affect other biota by changing the structure of the marine food chain.

(iv) Causes of mortality. Fisheries management is essentially a management of fishery induced mortality rates relative to those arising from other causes. Estimation of all significant mortality rates is therefore important. That generated by the fishery is of the first importance and is often obtained as a concomitant of the monitoring of abundance. For both the estimation of abundance and mortality, total commercial catch (both landed catch and discarded by catch) data are of the first importance. Other significant sources of mortality may include those from predation, disease or adverse environmental conditions. Suitable monitoring of these includes collecting stomach content and feeding data, conducting disease and parasite prevalence surveys and by recordings and appropriate investigations of anoxic and other fish kills. Tagging studies, sometimes including the use of smart tags, can be an alternative source of information on some mortality rates.

C. Forage and Nekton species (small pelagics, mesopelagics, squid, euphausids).

A number of these species have economic significance as the subject of fisheries and biological importance as sources of food to higher tropic levels. Many of these species are caught for fish meal and oil. Since these products are usually much less highly priced than fish for human consumption, the possibility of their harvest impacting that of commercial species may be of economic importance. Impacts of their harvest on top predators may also be of concern.

(i) Abundance and distribution. Much of the comment under commercial fish is also applicable to commercial species of small pelagics, mesopelagic fish and squid. However, since many of these species are annual or short lived species, monitoring methods are less often based upon sequential population analysis and more often based upon acoustic surveys, egg surveys or on depletion models of total catch. Since these species often have strong schooling behaviours, relative abundance estimates based upon commercial catch rates can be misleading. Stomach content of commercial fish species may be an alternative source of abundance data for some of these species. Distributional changes may be of particular concern for these species since they can react quickly to changing ocean conditions.

(ii) Reproduction. Comments under B apply.

(iii) Ecosystem role. These species typically act to transfer production from the plankton to higher trophic levels. Stomach content data of these species and of their predators may be important information in clarifying these processes. Some of these species may also prey on the egg and larval stages of commercial fish and shellfish.

(iv) Causes of mortality. Comments under B apply but these species may be dominated by predation mortality rather than by fishing mortality.

D. Benthos (commercial shellfish)

Benthos species such as crabs, crawfish, lobsters, prawns, shrimps, scallops, oysters, clams and whelks are frequently highly priced and of economic importance. Where they occur inshore they may also be of social significance as the basis of small scale fisheries.

(i) Abundance and distribution. Ideally these species would be monitored on the same basis as commercial fish. In some cases they form extensive stocks and are subject to fisheries similar to those for commercial fish (or even in fisheries with mixed catches of shellfish and commercial fish). In these cases similar monitoring approaches are indicated where they are possible. The lack of hard parts suitable for aging material may however be a limitation on the methods that can be used upon crustacea . In other cases these species, which often inhabit near-shore areas, form small local stocks subject to small local fisheries. These are less easy to monitor in a cost effective fashion. Monitoring through commercial catch rates may be one of the few practical options in these cases. Other options are diver surveys, beach surveys, research surveys, etc.

(ii) Reproduction. Reproduction studies have not so far been prominent for these species though some studies of larval drift have been made for some species.

(iii) Ecosystem role. These species may have roles as prey and as scavengers. Rather fewer will have roles as predators. The planktonic larval stages of some species may be particularly important as food sources. Some benthic species provide physical structure to the benthic environment.

(ii) Causes of mortality. As with commercial fish species, understanding of fishing mortality is important.

E. Habitat

Healthy coastal habitats are essential to sustained provision of ecosystem goods (such as fish) and services, and many fishes use coastal and inshore habitats for feeding and spawning, and as nursery areas. Habitats such as mangroves, coral reefs and sea grasses sustain particularly diverse and productive ecosystems, and these systems are often threatened by anthropogenic activities. On the continental shelf, benthic habitats such as rock, cobble and sand bottoms can be affected by mobile fishing gears. Seamounts and deep-sea habitats are characterized by high species endemism, and these habitats have been increasingly affected by fishing activities.

Monitoring of habitat should focus on changes in areal extent over time. Areal extent of many habitats such as coral reefs, seagrasses and mangroves can be assessed routinely using remote sensing, augmented with field surveys as required. Others, such as benthic habitats on continental shelves, can be assessed using side-scan sonar and other acoustic technologies. Monitoring of seamounts and deep-sea habitats will rely mainly on ROV's.

F. Zooplankton

Zooplankton includes the early life stages of fish, nekton and benthos as well as numerous species which permanently reside in the plankton and whose distribution is controlled mainly by currents. The residency of developmental stages in the plankton varies from days to months or longer, and the size of zooplankton varies from millimetres to jellyfish which may be over one-half metre in disk diameter alone. The smaller components are essential parts of the food chain leading to commercial fish while gelatinous zooplankton may provide an alternative food chain. The successful reproduction of some copepods, important food for developing fish larvae, is related to the timing and magnitude of spring phytoplankton blooms. Thus variations in zooplankton abundance and occurrence can affect the survival of higher trophic levels. At times swarms of gelatinous zooplankton may foul fish nets and there is evidence that fish avoid these areas. In other regions it has been reported that zooplankton are considerably less abundant where swarms of jellyfish occur but the interactions between the two are unclear. Thus the long term monitoring of this component of the ecosystem may well indicate wide scale processes that effect human activities.

Monitoring zooplankton is usually conducted by plankton surveys organized as time series and using towed or vertically hauled nets as the usual methods of collection. This includes the monitoring of standard sections such as the CalCOFI survey and the Continuous Plankton Recorder (CPR) survey, using ships-of opportunity or survey vessels. Recent developments of automated techniques for sampling include multiple opening and closing nets with environmental sensors, video and optical plankton recorders and acoustic and laser surveying instruments.

The variables that need monitoring are abundance, preferably by major taxa and size group, distribution (areally and vertically), reproduction and mortality. Secondary production estimates for zooplankton, although an important parameter, require controlled shipboard experiments on important species combined with field measurements of their abundance, fecundity and food.

G. Phytoplankton

Phytoplankton is the basis of life in the sea and changes at this level can affect all higher components of the food chain. Through toxic blooms, red tides and anoxia-inducing blooms phytoplankton can also give rise to risks to human health, to the survival of farm fish, shellfish, and top predators. Some of these questions are addressed by the IOC Harmful Algal Bloom Panel in its *Manual on Harmful Marine Microalgae* published in 1995. Phytoplankton can cause nuisances such as beach foaming and fouling of commercial fishing nets in some regions. Growth rates can be very high resulting in bloom conditions within days under favourable conditions of nutrients and light.

Monitoring of phytoplankton biomass is typically carried out by periodic measurements of extracted chlorophyll-a from water samples, and the 14-C carbon method is used for determination of primary production. Automated fluorescence measurements for chlorophyll-a can be made from underway vessels using continuous flow fluorometers, as well as from fixed or drifting buoys. Community composition is determined through cell counts in order to recognize microalgae species that could lead to harmful algal blooms. Natural populations can be also separated and identified at sea using flow cytometry techniques. Satellite sensors record ocean colour from which chlorophyll concentrations can be estimated and primary production roughly approximated.

II. Elaboration of Ecosystem Conditions

H. Nutrient Chemistry

The concentrations of inorganic compounds of several elements - e.g. nitrogen, phosphorus, silicon, iron - limit primary production in many oceanic locations, so knowledge of their concentrations and distributions can contribute to understanding of changes in the higher trophic levels. Concentrations are commonly measured by standard methods in discrete samples collected by water samplers. Underway shipboard sampling via pumping systems has been used with varying success. In situ measurements from towed instruments are currently under development. There are presently no methods available for remote sensing of these elements.

Repeated sampling (e.g. several day to monthly scale) of near-surface layer concentrations in areas of high and variable productivity (e.g. in coastal upwelling systems) may be one way to monitor potential production in such locations. On very much longer time scales (e.g. decadal), evidence should be sought for basic changes in fluxes (i.e. rates of supply to near surface layer). On these scales, changes in basic characteristics of nutrient/depth profiles in the upper permanent pycnocline may be essential information.

Logically, the presumed relation between changes in nutrient concentrations and in primary productivity is a reasonable hypothesis, and one that has guided classical biological oceanographic research to a substantial degree. However, until now there has been little documented success in relating variations in measured nutrient concentrations to substantial temporal variability in the biological ecosystem, with the result that there is little discriminatory power to separate major cause-effect linkages from mere co-variation. However, this may be simply the result of absence of appropriate information on nutrient variability.

One can say that the linkage of variability of nutrients or nutrient fluxes to variability in the biological ecosystem must mainly be through the effect on phytoplankton growth (primary production) and linked effects on distribution, concentration, and quality of phytoplankton cells. The likelihood that some of the information content may be more easily accessible at the level of the distribution and concentration of chlorophyll (easily sensed remotely), and through the likewise relatively easily sensed and modelled major physical driving forces for nutrient fluxes (wind-induced upwelling and turbulent mixing, tidal mixing, etc.) may influence the choice of the most appropriate allocation of resources in this instance.

I. Temperature, salinity, dissolved oxygen

The magnitude of temperature and the concentrations of dissolved salts (salinity) and oxygen are useful measures of physical structure and mixing as well as having inherent importance, for example in relation to the rates of biological and chemical processes. Certainly, temperature is the most easily measured environmental variable and as such forms a primary matrix for temporally and spatially continuous ocean monitoring, against which observations of other quantities more difficult to measure may be viewed and interpreted.

Temperature and salinity are commonly measured by instruments in situ (e.g. the CTD probe), giving continuous distribution vertically. Towed instruments, in some cases capable of profiling, can give continuous records horizontally. Dissolved oxygen has traditionally been measured in discrete samples, but oxygen sensors analogous to those for temperature and salinity are coming into use.

Sea surface temperature (SST) is commonly measured from satellites, giving large-scale continuous coverage in space with frequent repetitions of time. In addition to temperature itself, the delineated spatial patterns are potentially useful in diagnosing key processes (frontal structure, topographically-trapped water parcels and structures, etc.). The capability for satellite measurements of salinity has recently been demonstrated.

For SST, conventionally-achieved levels of accuracy and precision are generally adequate for use in specifying ecosystems. However, some consideration should be given as to whether the levels of accuracy over the decadal scales crucial for LMR-GOOS are preserved in the usual longer-term means and large-scale spatial composites.

A particular need for many aspects of LMR-GOOS is to define conditions at the floor of the continental shelf. Organisms in the pelagic environment are able to adjust their depth level to find acceptable conditions in a stratified environment. However, at the solid surface of the very gently sloping continental shelf floor, small vertical movements (meters) of the isopleths of key quantities may displace the intersections of those isopleths with the sea floor by large horizontal distances (e.g. up to tens of km), potentially displacing large segments of the extremely important biological community living at that interface. Well-founded procedures for merging various types of data (satellite, available vertical profiles, models, etc.) to extend the coverage to such depths would be extremely useful.

In certain shelf regions of the world's oceans, the distribution of low oxygen conditions on the continental shelf floor may have such dramatic effect as completely to overwhelm all other considerations. For example, it has recently been reported that two billion hake, a valuable commercial species off southwestern Africa, were recently destroyed in a single episodic outbreak of low oxygen waters over the shelf, completely disrupting the fishery and undoubtedly having major associated ecosystem effects (including documented sharp increases in mortality and corresponding declines in regional marine mammal populations).

J. Ocean velocity field

Ocean currents are responsible for advection of heat, dissolved materials, and particles (including fish larvae and other plankton), for mixing, and for formation of mesoscale structures such as eddies and fronts. Most marine organisms have complex life cycles with at least one planktonic stage. Many populations have developed highly adapted strategies for maintaining population under "normal" flow conditions. Highly anomalous flow conditions are thus expected to disrupt these strategies.

Horizontal flow can be measured directly at fixed locations (Eulerian measurements) or with drifters (Lagrangian measurements) and can be estimated indirectly, for example from the distribution of temperature and salinity. Remote sensing of sea surface height (altimetric measurements) can provide an indirect estimate of surface flow. Vertical flow, as in upwelling, is not presently measured directly, but is estimated from horizontal measurements.

Sea level measurements from coastal tide gauges and bottom mounted pressure sensors deserve mention here. In addition to providing information on ocean flow conditions, variations may also reflect alterations in the depth-integrated temperature and salinity fields. In general, such measurements are potentially highly useful for LMR-GOOS for all time scales of potential interest. New long-term implementation of sea level gauges on areas of coastline where such information is currently lacking, should be considered as a potentially cost-effective source of valuable information.

The difficulties in adequately specifying the richly-structured and variable ocean flow field may be mitigated to some degree by mechanistic modeling in conjunction with observations of more easily observed "tracers" of flow effects (SST, ocean color, etc.) and of the driving forces (wind, sea level height, etc.)

K. Atmospheric forcing

Surface ocean currents are largely wind-driven, and wind forcing is responsible for divergences associated with upwelling and with vertical mixing. Surface winds are commonly measured at discrete locations, e.g. from ships and shore stations and can also be measured (by scatterometer) from satellites. Atmospheric pressure measurements, usually from ships and shore stations, can be used for indirect estimates of surface winds and as indicators of large-scale processes, as in the Southern Oscillation Index (SOI), North Atlantic Oscillation (NAO) and indices of Aleutian Low behaviour. Meteorological agencies employ complex procedures for merging pressure and wind observations together with known physical laws to maximize continuity on short time scales. While the resulting data fields represent a potentially useful data source for LMR-GOOS, it should be kept in mind that these methods are designed specifically to support short term weather forecasting and that the long term homogeneity of the time-series of archived data fields as indications of the more subtle longer term trends underlying the energetic synoptic-scale variability may be a minor consideration for these agencies. Also, the spatial spreading of information inherent in these methods may mask significant real spatial variability.

In terms of direct measurement systems, the time scale again may be a crucial consideration. For example, scatterometer measurements of meso-scale wind stress curl patterns will be valuable on the "atmospheric event" scales but may not adequately define more subtle seasonal and interyear variability. This is a severe problem because important linkages of wind to ecosystem process are most often nonlinear. Identification of significant interdecadal variations may ultimately depend on the very large-scale "integrating" indices (SOI, NAO, etc.), implying a corresponding loss in interpretability of process details.

These are important considerations for the design of LMR-GOOS because of the importance of valid indicators of atmospheric forcing as proxy, or "derived," indicators of quantities (e.g. ocean flow, nutrient fluxes, etc.) more difficult to measure.

- Note on integrated analysis of ecosystem variation

Information on the causes of the distributions of separate classes of environmental parameters is also desired but is generally the result of analysis rather than of measurement. Changes in concentrations of nutrient elements can result from physical advection and mixing and from biological activity. At a given location, temperature and salinity can be changed by local processes (heat and water exchange) or by advection. Dissolved oxygen is modified by both physical and biological processes. Ocean currents are largely wind driven and their changes result from changes in wind forcing. Surface winds reflect large scale processes of heat exchange with the underlying surface, land or water, and changes in incoming radiation.

ANNEX II

REGIONAL MONITORING SYSTEMS

2.1 OPEN OCEAN SYSTEMS

A. Introduction

Physical Features

Generally homogeneous, the open ocean system is characterized by large basin-scale semi-permanent convergent frontal features that form the primary biogeographic boundaries in the otherwise featureless open ocean. Often dominating the flow field at these large scale fronts are mesoscale meanders, eddies, and frontal jets that serve as localized regions of higher productivity and aggregation for many of the dominant biological resources.

Dominant Biological Resources

Top predators include highly migratory finfish, marine mammals, and some sea turtles. Smaller surface pelagics such as sauries, squid, and pomfrets, as well as some sea turtles and seabirds may dominate in regions adjacent to fronts. The smaller pelagic fishes typically form the forage base for aggressive predators (sharks, billfish, large tunas, toothed whales) with high energetic requirements. For most other top predators (e.g., baleen whales, dolphins, seabirds), vertically migrating micronekton (ca. 2-10 cm in length) form the forage base.

Population Fluctuations and Environmental Influences on Living Marine Resources

In addition to fishing pressure, populations of dominant biological resources in the open ocean system, are most subject to natural large fluctuations on varying temporal scales (e.g., decadal and multi-decadal). Strong correlations have been shown to exist between interannual and decadal climate variability of water masses and circulation and “booms and busts” in the stocks of fish species.

B. Monitoring Requirements

The monitoring system that follows is intended as a minimal system, however, because of the enormous vertical and horizontal scales involved in the open ocean, observational monitoring will require considerable integration of resources. A composite picture at quarterly intervals could be built on the framework provided by the satellite data and transect observations, with the irregular biological data inserted where applicable. The spatial scale of in situ observations made in the vicinity of open ocean boundary features should be much closer, e.g., 100 km or less, than in the central ocean gyre regions, e.g., 300 km or more. Analyses, which would provide the basis for elaboration of useful products, would be made at appropriate basin-scale regional analysis centers.

I. Atmospheric and Oceanographic Information

(i) Atmospheric information:

- As with the coastal monitoring, time series of atmospheric pressure and wind patterns to enable monitoring of basin-scale and long-term variability. In situ sampling, surface and satellite remote sensing and numerical models can provide this information.

- Surface weather elements reported by voluntary observing ships reporting to the WMO network.

- Basin-scale atmospheric indices (e.g., Pacific Decadal Oscillation (PDO), North Atlantic Atmospheric Index, ENSO) are computed and monitored to identify low frequency changes.

(ii) Oceanographic information

The horizontal and vertical expanse of the open ocean requires multiple platforms for oceanographic monitoring. The program would integrate information from space-borne satellite remote sensing (e.g., SST, sea level height (SLH), ocean color), bio-physical oceanographic moorings (e.g., NPac series, TAO array), Argo floats, shipboard sampling, and numerical models. Shipboard sampling includes regular oceanographic research cruises (transects/time series e.g., Hawaii Ocean Time Series (HOT), Bermuda Atlantic Time Series (BATS), fishing vessels, and ships of opportunity. On transects selected to cross major features of circulation or of changes in properties (e.g., ocean fronts), selected merchant and research ships would tow plankton recorders and drop expendable bathythermographs (XBTs) at appropriate intervals (e.g., hourly). For monitoring, time series of selected parameters for all platforms will be constructed and maintained.

<u>Physical Variables</u>

As a minimum, the temporal and spatial distributional patterns of the physical thermohaline variables (temperature, salinity, density) and ocean currents must be monitored throughout the world ocean regions where major fisheries operate. This is especially true in the vicinity of high gradient oceanic fronts and mesoscale perturbations (e.g., meanders, eddies, jets) that create boundaries in an otherwise featureless environment. Ocean currents on the large scale can be inferred from satellite altimeters or ocean circulation numerical model output. On smaller scales, direct observations (e.g., ADCP) or moored current meters will provide data.

<u>Chemical Variables</u>

Nutrient availability in lighted open ocean surface waters is generally tightly coupled to prevailing physical oceanographic conditions, especially in the vicinity of fronts. Information on the macronutrients, principally N, P, and Si, available to primary producers is necessary for modeling efforts and understanding patterns of productivity and geochemical flux and balance. In open ocean environments, ambient dissolved oxygen concentrations are important to the distribution of high energy animals, e.g., tunas. Information on nutrients and dissolved oxygen would be collected on an irregular basis by research vessels.

II. Plankton Information

- Phytoplankton: species composition and distribution (abundance and biomass)

Ocean color from multispectral spaceborne satellite sensors (e.g., SeaWiFs, MODIS) will provide large scale (global-, basin-) surface phytoplankton information in the open ocean. Additional near surface data will be supplied by optical drifters, particularly on the mesoscale, and by-in-line fluorometric sensors aboard research vessels. Phytoplankton dynamics through the water column are examined through shipboard surveys and biophysical moored arrays. Minimally, chlorophyll measurements (*in vivo* or extracted) would be made through fluorometry or spectrophotometry to estimate phytoplankton biomass. Where possible, phytoplankton composition can be characterized through visual taxonomy or from diagnostic markers through high performance liquid chromatography (HPLC).

- Zooplankton: species composition and distribution (abundance and biomass)

Information on zooplankton would be irregularly collected through net sampling and where available, optical plankton counters (OPCS) and electronic plankton counters (EPCS) principally by research vessels, and plankton recorders on research vessels and ships-of-opportunity. As much as possible, net sampling should be standardized, and it would be advantageous to maintain some consistency with internationally accepted zooplankton sampling protocols. Where possible, information on species composition and abundance of epi- and meso-pelagic micronekton (1-10 cm in length) needs to be collected because of their role as forage for pelagic species.

III. Fisheries Information

Most information on the abundance and distribution of open ocean top predators and commercial exploited resources (nekton) will be reported by fishing (or fishery observers) and research vessels. As with environmental parameters, time series of patterns need to be constructed and maintained. Minimal data includes fleet catch and effort, landings, distribution of catch and effort, and discards for commercial species and incidental bycatch (including protected species). Additionally, basic fishery data information on length, weight, and sex for individual animals is necessary.

IV. Fish Biological Information

Coupled with the fisheries information is the need for an understanding of life history and ecology. This requires biological samples to address reproduction and maturation (gonads), age and growth (otoliths, statoliths, etc.), feeding (stomachs), and movement/migration.

V. Predator Monitoring

Similar information is required for marine mammals, sea turtles, and seabirds, including population strength, reproductive success, feeding ecology, sightings, and capture rates. These data are typically difficult to come by and usually will require dedicated efforts.

VI. Monitoring Scheme

- Satellite observations of large-scale oceanographic (frontal) features over varying temporal scales.
- Establish and maintain time series transects that will represent “cross” regional characterization.
- Assess abundance of living marine resources annually against the background of basin-scale indices.

C. Modeling Requirements

Numerical production models, particularly for primary production, perform well in open ocean systems and will continue to improve. Where available, empirical production estimates will be applied to ground-truth model output. Traditional population assessment and simulation models need to better incorporate environmental information. Future data assimilation techniques should move towards an ecosystem based model.

2.2 COASTAL FISHERIES IN UPWELLING SYSTEMS

A. Introduction

<u>Physical Features</u>

Eastern Boundary Systems are elongate systems where cool waters extend into tropical and subtropical waters on the western side of continents and are generally the region of highest productivity in the particular ocean basin. Despite considerable exchanges across their boundaries, they are regarded as distinct ecosystems characterized by high physical and biological variability at all time scales. The high fish yields, abundance of top predators and influence on climate make them extremely important to the economies of coastal states and target areas for monitoring to be selected as part of the GOOS program. The enrichment process is driven by wind-induced upwelling and so is highly variable and subject to large-scale changes in the medium and long term in response to climate change. The open boundary nature of these systems make them sensitive to basin scale variability and intrusions of warm and cool water shift boundaries at the extremities. In addition oceanic water may intrude close to the coast during periods of wind relaxations, considerably altering the habitat range and productivity of the living marine resources.

<u>Dominant Biological Resources</u>

Typically, upwelling systems are dominated by a few species of small schooling pelagic fish, such as sardines, anchovy and jack mackerel. These planktivorous fish feed low down in the trophic foodweb and are subject to extremes in population strength, with marked influences both on lower and higher levels in the food chain. They are therefore the focal point of variability and the food webs are termed “wasp-waist” ecosystems. In addition to the forage fish, demersal species such as hake and pelagic predatory fish such as tuna, sharks and skipjack or bonito are abundant. Top predators such as gannets, cormorants, penguins, pelicans, dolphins, seals and whales feed directly on the small shoaling species. Inshore benthic and intertidal organisms such as rock lobster, abalone, mussels and seaweeds developed high population biomass in the highly productive waters. Low oxygen concentrations develop in the complex recirculation patterns which characterize the shelf regions of upwelling systems and so limit the offshore extent of high macrobenthic invertebrates. Eastern boundary systems are therefore dominated by trophic flow within the pelagic ecosystem.

Population fluctuations

Recruitment fluctuations drive the major changes in population strength of small pelagic species, which have very specific adaptations in each upwelling region to ensure successful spawning and survival. Fish select specific areas and seasons to reproduce and the triad of enrichment, concentration and retention processes have been identified as important mechanisms which influence successful reproduction. The regions where these three factors are optimised in upwelling systems have been termed “Biological Action Centers” (BAC’s). Species life history strategies, such as feeding, spawning, recruitment and nursery functions, are closely linked to these active centers. Fish select spawning areas which will minimise offshore losses and ensure the maximum retention of larvae and juveniles in productive areas. Several such optimal habitats may exist within any upwelling ecosystem and usually comprise an active upwelling center, a coastal embayment and a considerable amount of recirculation, with marked fronts and eddies.

While the top predators have sufficient mobility to overcome advective processes in upwelling regions, similar restraints to spawning success apply to the predators that have pelagic eggs and larvae. Birds and seals have land-based breeding areas that provide good opportunities for conducting monitoring of population status.

Environmental Influences on Living Marine Resources

Large scale variability may alter the circulation and productivity of these BAC’s, or fishing activities may reduce some of the subpopulations using different BAC’s to extremely low levels, or there may be shifts in dominance from one species to another, e.g. sardines to anchovy. The subdominant species or population group may be subject to the “schooltrap” and be forced to utilise suboptimal reproductive or feeding strategies and so remain at a low population level. Therefore monitoring and modeling ecological processes within and between these centers is a focus of the proposed monitoring in the eastern boundary current ecosystems.

B. Monitoring Requirements

Upwelling systems, subject to high variability over a range of scales, require different spatial and temporal scales of sampling than either temperate regions or enclosed seas. However, monitoring requirements in these areas comprise the same items as considered in other ecosystems.

Upwelling Ecosystems generally comprise an elongate coastline with a series of Biological Action Centers (BAC´s), where spawning, transport, nursery and feeding are more successful than in intervening regions. Examples of subregions where enhanced fish production occurs include Vancouver Island, southern California Bight and Sebastian Viscayno Bay in the California Current Region; North-central Peru, Iquique-Antofagasta, Coquimbo and Talcahuano in the Humboldt; the Angola-Benguela front, the Palgrave Point Region, St Helena Bay and the western Agulhas Bank in the Benguela; and Tan-Tan, Dhakla, Bank d´Aguin and south of Cap Vert in the Canary Current. These areas are the focus of the monitoring and observation activities.

I. ATMOSPHERIC AND OCEANOGRAPHIC INFORMATION

(i) Atmospheric Information

Time series can show the large-scale variability of atmospheric pressure and winds. Smaller scale variations can be derived from models.

Calculations drawn from the above variables can be used to construct a time series of Wind stress, Ekman transport, Upwelling indexes, anomalies, etc.

Basin-scale atmospheric indices can be derived, for example: North Atlantic Atmospheric Index, SOI, and ENSO.

(ii) Oceanographic information

The oceanographic information could be collected either at coastal stations (time series) and/or by regular oceanographic cruises using research or fishing vessels, and ships of opportunity (spatial information) and a minimal number of strategically placed buoys. Satellite information on SST and Ocean Colour is also necessary.

- Physical & Chemical Variables: temperature, salinity, dissolved oxygen, chlorophyll-a, ocean colour and particle size. It is necessary to establish the temporal and spatial distributional patterns of physical and chemical variables in upwelling systems; on adequate scales of observation, to relate with atmospheric forcing and, on the other hand, with biological observation of the ecosystem.

- Currents: If it is possible, it would be desirable to know general circulation patterns inferred from the geostrophic field, direct currentmeter measurements, ADCP measurements or hydrodynamics models applied to an specific upwelling region.

II. Plankton Information

Plankton information could be collected, as is oceanographic information, using a nearshore regular time series and regular oceanic cruises carried out simultaneously with the physical data or during fisheries surveys. Crude measurements of phytoplankton and zooplankton size distributions are useful indicators of community changes, but detailed more time-consuming identification of species is required to adequately characterise the changes. On monitoring transects through selected regions, the following information is necessary:

- Phytoplankton: species composition and distribution (abundance and biomass)
- Zooplankton: species composition and distribution (abundance and biomass)
- Primary and secondary production (if possible)

III. Fisheries Information

The fisheries data required to construct a time series could be derived from:

a. fishing fleet local discharge (all species present);
b. distribution of catch and effort;
c. on board fishing vessel (all species present in each fishing cast, including discard species); it is desirable to coordinate on board sampling of some basic physical and biological information. For example TS profiles, plankton, acoustic scattering layers, presence of predators, etc.;
d. fishery independent observation, i.e., fishery research vessel or regular fishing boat dedicated to conducting oceanographic and biological cruises.

The minimum fish data needed for each fish species present are: catch (unit weight), length, weight, sex, macroscopic sexual maturity states, stomach contents, otoliths, and gonad weight.

The basic fish data could be used to estimate:

- length-frequency (in time and space if possible)
- Length-weight relationship
- Fishing effort
- Recruitment variability
- Direct and indirect stock assessments (i.e., acoustic, EPM, VPA)
- Discard
- By-catch
- Stock units identification

IV. Fish Biological Information

- Reproductive aspects (i.e., spawning area and period)
- Early developmental stage variability
- Physiological index
- Feeding behaviour
- Fish school behaviour (i.e., migration rates)
- School composition

V. Predator Monitoring

- Population strength (at rookeries)
- Breeding or fledging success
- Diet composition
- Sightings
- Capture rates

VI. Monitoring Scheme

The essence of the monitoring scheme is to detect changes in abundance of dominant organisms, in the distribution of spawning habitat, and in ocean structures and processes. Many pelagic species expand and contract their habitat range as population biomass alters and this is one of the most important diagnostic parameters in Eastern Boundary systems.

- Satellite observations of boundary and frontal features on daily, weekly, seasonal, interannual and inter-decadal scales. The minimum temporal scale can be determined by the frequency of cloud-free images available.
- Monitoring of selected transects in important habitat areas (BAC's) at monthly or bi-monthly time scales for oceanographic and biological parameters.
- Surveys of spawner or recruit biomass or egg abundance and distribution of pelagic species throughout their range, with complementary environmental and biological information.
- Demersal surveys of trawlable stocks, with acoustical surveys above the bottom boundary layer once or twice per year with complementary environmental and biological information. Species identification and length frequencies of the entire sample.
- Fishery-independent surveys of other benthic species, e.g. crabs, lobster, abalone, intertidal organisms annually .
- Monitor species composition, length-frequency and landings of artesanal net and line-fisheries at daily/ weekly intervals
- Assess abundance of top predators such as birds, seals (aerial photography), dolphins (sightings) sharks, tuna (catch records) at annual intervals.

These measurements can be assessed against the background of basin-scale indices such as ENSO, SOI , NAO, changes in zooplankton indicator species which are readily available over the internet. However the internet is a necessary, but not sufficient source of monitoring information for Eastern Boundary Currents.

C. Modeling Requirements

Modeling serves principally as a diagnostic tool and in the future data assimilation techniques and predictive models need to be developed in order to anticipate changes in ecosystems.

- Physical simulation models of the essential dynamics of each BAC system, into which can be nested Individual-Based Models (IBM).
- Monthly Sequential Population Analysis

- Growth Modeling
- Larval Growth and Mortality
- Stock-Recruitment Modeling
- Trophodynamic Modeling
- Zooplankton stage-based population models

D. Capacity Building Requirements

- Acoustic technique training (fish and plankton)
- Otolith reading – age validation and quality control
- Reproductive staging skills

2.3 MONITORING OF THE SCOTIAN SHELF ECOSYSTEM OFF ATLANTIC CANADA

A. Introduction

Physical Features

The Scotian Shelf ecosystems cover about 185,000 km^2 of continental shelf (<400m) off the southeast coast of Canada. Characterized by complex bottom topography with numerous offshore shallow (<100 m) banks and deep (>200 m) basins, are separated from the southern Newfoundland Shelf by the Laurentian Channel and border the Gulf of Maine to the southwest. Surface circulation is dominated by a southwestward flow with low salinity waters from the Gulf of St. Lawrence discharging onto the Scotian Shelf on the south side of the Cabot Strait. Part of this flow rounds Cape Breton to form the southwestward moving Nova Scotia Current on the inner half of the shelf while the remainder flows along the Laurentian Channel, turns at the shelf break, and eventually enters the Gulf of Maine through the Northeast Channel. The amplitude of the annual cycle in sea surface temperature (16 ^oC, Petrie et al. 1996) in the region from the Laurentian Channel to the Middle Atlantic Bight is the largest anywhere in the Atlantic Ocean (Weare, 1977) and one of the largest in the world.

The vertical structure of the water colomn on the Scotian Shelf undergoes large seasonal variations. In winter, strong winds and cold air temperature result in rapid heat loss and water becomes vertically mixed to depths of 50-150 m. In spring and summer, solar heating combined with reduced salinity (due to ice melt and advection), make the surface waters less dense and lead to rapid stratification, trapping the cold, winter-mixed water below. In the central and western shelf generally warm offshore slope water (a mixture of Gulf stream and Labrador current waters) moves in along the bottom beneath the winter-cooled waters because the offshore water is more saline and hence denser. The winter-chilled cold intermediate layer (CIL), with temperatures varying from 2-5 ^oC, is sandwiched between warmer surface and bottom layers. The relative proportions of warm Gulf Stream and cold Labrador Current waters comprising the slope water determine whether incursions of this water have a cooling or a warming effect. The amplitude of the North Atlantic Oscillation (NAO) is implicated in the relative volumes of these two water masses in the slope water. A significant difference between the western and eastern shelf is that on most of the eastern Scotian Shelf bottom topography prevents the warm offshore waters from penetrating inshore and the CIL (<5 ^oC) extends to the bottom depths >200 m).

Therefore, bottom temperatures vary from 2-4 ^{o}C in the northeast to 8-10 ^{o}C in the deep basins in the centrel and west (Zwanenburg et al. 2000). There are little to no seasonal variations at these depths.

Annual changes in near bottom temperatures on the Scotian Shelf are among the most variable in the North Atlantic. Near bottom waters of the western shelf generally remained warmer-than-average from the 1970s to 1997. The highest sustained temperature anomalies in the approximate 50-year record were observed in the mid-1990s. In 1998, cold Labrador Slope water again appeared with a subsequent lowering of temperatures in Emerald Basin by over 3 ^{o}C (Drinkwater et al., 2000). From the late-1960s to the mid-1970s, bottom temperatures in the northeast oscillated near or above average. They rose above normal around 1980 but by the mid-1980s, temperatures fell sharply. Below approximately 50 m, temperatures have generally remained colder-than-normal and the coolest in the approximately 50-year record occurred in the early 1990s. In recent years, the waters have been warming and are now approaching normal.

Dominant Biological Resources and population fluctuations

Fauna of temperate shelf systems such as the Scotian Shelf are relatively diverse and biomass is distributed over a wide range of trophic levels from marine mammels to interstitial benthic meiofauna. Fish fauna is the best studied and relatively species rich (100+ species) with dominance alternating between demersal and pelagic types over time. Overall contributions of primary, secondary and benthic productions to system biomass are not well understood because of a lack of synoptic monitoring at these trophic levels. The eastern and western parts of the Scotian shelf are considered closely linked but separate ecosystems because of differences in physical environment and in fish and invertebrate communities. The different temperature regimes also result in differences in growth rates for trans-shelf species. The eastern shelf fishes have traditionally been dominated by cod (*Gadus morhua*), redfish (*Sebastes spp.*), haddock (*Melanogrammus aeglefinus*) and American plaice (*Hippoglossoides platessoides*), while the western shelf fishes are dominated by dogfish (*Squalus acanthias*), haddock, redfish and pollock (*Pollachius virens*). Zwanenburg et al. (2000) show that over the past three to four decades, there have been changes in the abundance and distribution of many marine species on the Scotian shelf. In both areas biomass and average size of demersal fishes have decreased significantly, particularly in the past 15-20 years. Some demersal fish populations have declined precipitously (particularly true of the commercially exploited species like cod and haddock) while at the same time the abundance of other species, both invertebrates, small pelagic fishes, and marine mammels has increased. These changes suggest that there may have been changes in the trophic structure of these ecosystems.

Although the changes in demersal fish abundance and species composition can be relatively well described, information on other trophic levels is less available. There are no synoptic time series of primary, secondary, or benthic production for the Scotian Shelf. Some data for specific years or for limited areas of the shelf are available but these are not sufficient to describe long-term dynamics. Information on biomass of dominant small pelagic species (mainly *Clupea harengus, Scomber scombrus)* is also inadequate due to lack of effective monitoring. Information on marine mammals is equally sparse with the exception of pinnipeds, in particular, grey seals, whose population has been increasing at a rate of some 12% per annum since the early 1960s (Zwanenburg and Bowen 1990). Large migratory pelagic fishes (tunas, sharks and swordfish) are seasonal transitory residents in these systems' whose dynamics are best described at ocean basin scales rather than the Scotian Shelf scale. Seabirds form an important component of both systems, however there is little information on changes in distribution or abundance.

Environmental Influences on Living Marine Resources

For the eastern shelf we observe significant increases in the abundance of cold-water species concurrent with the negative temperature anomaly of the last 15 years. We observed significant increase in the numbers of capelin (*Mallotus villosus)*, turbot (*Rheinhadtius hippoglossoides)* northern shrimp (*Pandalus borealis)*, snow crab, (*Chionoectes opilio)*, and sand lance (*Ammodytes dubius*). Although the increase in these species is partly attributable to the negative temperature anomaly, the low biomass of cod, a predator of all but turbot, must also be contributing.

Since the 1970s average weight of commercially targeted demersal fish decreased by 5l% on the eastern shelf and by 41% on the western shelf. For both systems the integrated community size frequency showed long-term declines in proportions of large fish, and trawlable biomass of most targeted species is presently at or near the lowest observed. In the east these changed were coincident with a doubling of fishing effort, and a decline in bottom temperature to the lowest in 50 years. In the west, fishing effort more than doubled while bottom temperatures reached the highest in 50 years. In both systems declines in biomass and average weight were more prevalent for commercially targeted species than for non-target species. Since the closure of the cod fishery in the eastern shelf in 1993 and the restrictions on landings on the western shelf, average weights and the integrated community size structure have stablized. In the east this stablility if associated with increasing bottom temperatures and reduced effort, while in the west it is concurrent with reduced landings and high bottom temperatures. Although both fishing and changes in bottom temperature have influenced demersal fish size, the relative effects cannot be determined from current observations.

Fishing and other human activities such as oil and gas exploration and extraction are conducted within this dynamic physical and biological framework. The systems “upstream” of the Scotian Shelf (Gulf of St. Lawrence and Grand Banks) are generally colder than more boreal systems. Although the causal mechanisms are still a topic of debate, a shift in the boundary between these systems and the Scotian Shelf was evidenced by the build-up of cold-water species especially on the eastern shelf during the late 1980s through mid 1990s. The interaction between Scotian Shelf and the adjacent open ocean system comes mainly through the incursion of warm-core rings, and entrainment of Slope waters.

B. Present Monitoring and Additional Requirements

I. Atmospheric and Oceanographic Information

(i) Atmospheric Information

- Air pressure;
- Air temperature;
- Geostrophic wind;

(ii) Oceanographic Information

- Freshwater inflow;
- Ocean features (warm-core rings, Gulf Stream and shelf-slope boundary positions);
- Ice/iceberg distribution;
- Monthly SST from ships of opportunity;
- Halifax SST;
- Monthly T-S series for Emerald Basin;
- CTD (conductivity, temperature, depth) profiles are collected from ships of opportunity. These include all major research cruises, including the annual groundfish trawl surveys.
  These casts provide extensive information on salinity and temperature profiles as well as bottom temperature over much of the Scotian Shelf seasonally;
- Sea level.

II. Plankton Information

- A time series from line E of the Continuous Plankton Recorder (CPR) program provides seasonal and decadal data on plytoplankton colour index and plankton species abundances. However, the series is discontinuous, with critical gaps during the putative 'regime shift'.
- <u>Additional requirement</u> for a more synoptic coverage of zooplankton diversity and production.
- <u>Additional requirement</u> for seasonal/annual estimates of primary productivity based on analysis of satellite imagery.

III. Fisheries Information

- Fishing effort by gear type and location (geo-referenced);
- Landings by species and location (geo-referenced);
- Size and age composition of landings for several commercially important species;
- <u>Additional requirement</u> for by-catch of non-commercial species caught during commercial fisheries or killed during other human activities, this is especially true of species that are deemed at risk of extinction.

IV. Fish Biological Information

- Commercial and non-commercial groundfish abundance, distribution, size structure, state of maturity and diet composition (annual trawl surveys 1970 to present);
- <u>Additional requirement</u> for number and locations of spawning locations is required;
- <u>Additional requirement</u> for selection differentials for certain commercially exploited species is required;
- <u>Additional requirement</u> for bottom areas disturbed by ocean use activities including fishing;

- Additional requirement for improved knowledge of species composition, abundance and distribution of benthic invertebrate fauna of disturbed and undisturbed areas. These invertebrates are not currently monitored and have not been well characterized;
- Additional requirement for distribution and abundance information on species at risk of extinction. Although present trawl surveys provide good information on distribution and abundance of most demersal fishes, small pelagic fishes, small demersal fishes, and demersal forage fishes are not well sampled.

V. Predation Monitoring

- Grey seal abundance;
- Additional information on condition abundance and food habits of selected key predators on forage species.

VI. Monitoring Scheme

Monitoring of marine ecosystems should be designed such that it detects changes in the abundance and distribution of at least the dominant organisors at all trophic levels. It should also detect changes in ocean structure and processes, particularly changes in boundary conditions with adjacent marine systems. The key is that the biotic and abiotic components of ecosystems are inherently dynamic exhibiting regular cyclical as well as random changes. Therefore, it is important to define what type of change is being sought and how to differentiate it from natural background noise. Discerning directional change and perturbations of cycles from regular normal change, and attributing causes to those changes, are essential especially for developing mitigative or adaptive responses to the changes.

C. Modeling Requirements

Over the past three to four decades, we have observed changes, at times dramatic, in enviromental conditions, exploitation, and the abundance and distribution of many marine species on the Scotian Shelf. Attempts to disentangle the fishery and enviromental effects leading to ecosystem change have, so far, been inconclusive. Multidisciplinary and ecological approaches are being undertaken to better understand the changes that have occurred in the Scotian Shelf ecosystems. Specifically, these projects are aimed at determining how the physical and biological components of these ecosystems have changed over time and space and what the relative conditions of environment and fisheries have been.

D. Capacity Building Requirements

The additional monitoring requirements are identified in Section B. Further capacity building requirements are discussed in the context of the retrospective analysis of Scotian Shelf monitoring reported in Section E.

E. Retrospective Analysis of Scotian Shelf Monitoring

At the second LMR-GOOS session, 23 – 25 March, 1999, it was recommended that several well monitored shelf seas that have been characterized by 'regime shifts' be evaluated in a retrospective sense. The monitoring program of the eastern Scotian Shelf in support of fisheries management was one of the case histories. The retrospective analysis was restricted to the 1987 to 1994 time period. During these years the cod stock in this area declined from moderate levels to the lowest on record. A moratorium on directed commercial fishing of this stock was put in place in September 1993. The North Atlantic Oscilliation (NAO) anomaly was strongly positive from the mid-1980s to the mid-1990s. During the same time period, major changes in the ecosystem occurred (see above). Thus the 1987 to 1994 time period brackets the decision-making period during which there was a 'regime shift', the cod stock collapsed and the fishery was closed. The analysis is published as Annex IV of GOOS Report No. 74. A summary of the monitoring program and the conclusions of the retrospective analysis are provided below.

The Scotian Shelf ecosystem has been monitored to some extent for over two decades. Monitoring includes the extensive list given in Section B and indicates that the monitoring activities focused on fishing, trawlable fish and invertebrates, grey seals and ocean/atmosphere physical parameters.

It was concluded that the monitoring program itself was adequate for the needs of the fisheries management system. The routine data collected on the fishery and during the annual trawl surveys were adequate to describe trends in fishing effort by area and gear type, changes in size and age composition of the landings, trends in cod abundance and geographic distribution, and trends in fish community distributions. The Grey Seal surveys provide excellent estimates of absolute abundance of an important fish predator. The environmental data (temperature, salinity, sea ice, atmospheric conditions, sea level, etc.) provide sufficient data to describe in near real-time the changing state of the ocean off Atlantic Canada. There were some gaps, including trends in plankton production added to the core-monitoring program in 1999 (Theriault et al. 1998).

It is instructive to separate out two functions of the monitoring program – descriptions of ecosystem change and understanding of what is causing the changes. The requirements of the former are much less stringent than the latter. The above listed monitoring activities are adequate to describe aspects of ecosystem and fishing changes (fishing patterns, seals, fish communities, state of the ocean/atmosphere). The program on its own was not, however, sufficient to interpret the causes of the cod collapse. It should have been sufficient to support the decision-making process in support of achievement of the conservation objectives of fisheries management.

There is a significant caveat to the above conclusions. A major complication in near real-time description of cod abundance changes and fishing mortality trends during the l987 to 1994 period was the change that occurred in cod natural mortality (M). Without a fishery since 1993, it has recently been possible to estimate M directly from the trawl survey data. The stock assessments had assumed a constant level of M (about 20% annually for ages that are fished). This assumption is now known to be incorrect, and a trend in M generates overestimates in abundance and underestimates in fishing mortality in the most recent years of the assessment. It is hard to imagine any monitoring program that could have allowed trends in M to have been described in near real-time. Thus there are clearly limits to what a monitoring program can capture.

It was concluded that the analysis of the monitoring data was inadequate. The reasons for the inadequate analysis were both institutional and scientific. Only part of the data available from the monitoring program was routinely analyzed; and some informative data products for fisheries effort, oceanographic properties and fish community information were only available in retrospect. It was also concluded that limits to theoretical understanding of ecosystem structure and function were (and still are) a constraint to the interpretation of the data products. Even with the benefit of hindsight there is considerable uncertainty in the causes of the recruitment collapse that started in 1983. The causes of the reduction in cod growth rate and poor fish condition are also not well understood. The observed trends in cod population characteristics are no doubt responses to a contribution of both over-fishing and ecosystem change. There are limits to explanatory power within marine ecology, even for major 'regime shifts' in a well monitored system such as the eastern Scotian Shelf.

Key points for LMR-GOOS are:

- The monitoring program itself was sufficient to describe the 'regime shift' changes in near real-time and to meet the advisory needs for fisheries management;
- The program was not sufficient to interpret the causes of the collapse of the cod stock, even in hindsight;
- Timely analyses of the full range of ecosystem monitoring data, and the generation of accurate data products, are essential for the provision of credible advice to fisheries management;
- This requires institutional structures that generate and review the data products for management needs.

<u>Changing needs for scientific advice</u>

The Convention on Biological Diversity (CBD), the Straddling Stocks Convention (UNFA), and the Code of Conduct for Responsible Fishing have generated broader conservation objectives for the management of ocean use activities. The 1997 Oceans Act obliges Canada to incorporate ecosystem objectives within an integrated oceans management framework. The pending legislation addressing species at risk of extinction will generate recovery plans for endangered marine species. Thus we are in a transition period with respect to the need for scientific advice on management of ocean uses (oil and gas, aquaculture, marine transporation, eco-tourism, recreational use and fisheries). Management will continue to occur at the sectoral level, yet the aggregate activities need to meet some yet to be defined ecosystem objectives. The scientific advisory context for LMR-GOOS is in transition. Fisheries management needs to take into account ecosystem considerations, and other ocean uses have impacts on the ecosystems that need to be evaluated in relation both to the fisheries impacts and the broader conservation objectives inferred under new international conventions and national legislation.

Ecosystem objectives, indicators and reference points

The ICES/SCOR Symposium on the Ecosystem Effects of Fishing, which was held in Montpellier in March, 1999, provided some guidance on a framework for the incorporation of ecosystem considerations within fisheries management. The Symposium overview paper (Gislason et al. 2000) lists six potential ecosystem objectives for ocean management, three address biodiversity and three habitat productivity. The traditional conservation objective for the target species of fisheries management is subsumed within the latter three. For each objective there will be a need to define indicators of relevance as well as reference points that trigger management action.

At a March, 2000, Canadian LMR-GOOS workshop at the Bedford Institute of Oceanography there was a detailed review and discussion of indicators for each of the six objectives. To the degree that a region wants to achieve a particular objective, LMR-GOOS for that ocean area needs to monitor properties that will generate data products on the relevant indicators.

Maintenance of ecosystem diversity

The benthos is considered separately from the pelagic component of the marine biota. Due to recent advances in multi-beam and side-scan sonar it is now possible to routinely map the bottom sediment type and define the number and geographic pattern of bottom communities in ‘benthic ecosystems’ that need to be maintained. The indicators to be monitored are (i) the spatial extent of disturbance (by fish gears, oil/gas operations, aquaculture sities, etc.) for each category of benthic habitat in the classification scheme, and (ii) benthic community properties in ‘no disturbance’ areas (MPAs) and disturbed areas for each benthic ecosystem type. For this objective it is assumed for planning purposes that some percentage of each habitat type would need to be undisturbed.

The indicators would be measures of geographic patterns in plankton and fish community structure. The present monitoring activities on the Scotian Shelf (CPR line, seasonal zooplankton net hauls on transects, ecosystem trawl survey from Cape Hatteras to Cape Chidley) should be sufficient to generate the data products.

Maintenance of species diversity

The minimum required for this objective is to provide indicators for the Recovery Plans of the species at risk of extinction. For the Scotian Shelf the species for which Recovery Plans are already in place, or are expected to be developed, are Right whale, Harbour porpoise, Leatherback turtle, Bay of Fundy Atlantic Salmon, and Nova Scotia ‘Uplands’ Atlantic Salmon. Other species of particular concern are sharks and skates (due to their low productivity) and possibly cusk. The indicators need to be considered at the geographic scale of evolutionary significant units, and are species specific. They include:

- Rate of population decline
- Contraction in distributional area
- Number of spawning components

- Number of individuals and effective population size
- ‘Integrity’ of essential habitat
- By-catch, or mortalities

Maintenance of genetic variability within species

The indicators for this objective have some overlap with that above, but need to be considered for a much wider range of species, in particular for species that are commercially exploited. There are at least two high profile concerns, the loss of spawning components and the reduction in genetic variability within populations (both due predominantly to fishing practices). The indicators include:

- Number of populations for exploited species
- Sex ratio
- Selection differential for life history parameters such as size-at-age and age-at-maturity
- Nearest neighbour estimates for sessile invertebrates

Maintenance of directly impacted species

This objective subsumes the need to prevent growth and recruitment overfishing of the commercial species targeted by the diverse fisheries on the Scotian Shelf. The targeted indicators are:

- Spawning stock biomass (B)
- Exploitation rate (F)
- Recruitment Trends

Recently there has been a move to broaden the scope of the indicators to include such measures as:

- Size/age composition of landings and of the population
- Weight/length at age
- Condition factor
- Areal distribution of landings and of the population
- Fishing effort
- Compliance of fishers
- Enforcement capability

With the use of a broader range of indicators a qualitative traffic light approach (green/yellow/red ratings by indicator) is envisioned, which would complement the present use of quantitative assessment models. The traffic light approach (Caddy 1999) considers the state of an array of variables or indicators relevant to the status of individual fish stocks, or at a higher-level organisation, the status of the ecosystem as a whole. To evaluate the status of system, the state of each variable is evaluated relative to a limit reference point, if defined, or to its historical dynamic range. The state of each variable can then be judged as either good, bad or intermediate (red, green or yellow) and the integration of the states of all variables gives an indication of the status of the system. The value of this approach is that it allows incorporation of a broad array of indicators into the determination of ecosystem status. It also allows for both qualitative and quantitative measures to be evaluated in a single framework within which judgements on reliability, accuracy, or importance of each indicator can be explicitly defined. The traffic light approach could allow for truly integrated evaluation in that it could incorporate stock indicators, ecosystem indicators, economic and social indicators, and indicators of regulatory compliance. Within such a framework ecosystem considerations or objectives can be defined as limit or target values for integrals of an array of indicators.

Maintenance of ecologically dependent species

This objective addresses the importance of food-chain interactions amongst the target species of commercial fisheries and the key predators and such species. It is of particular interest for fisheries on forage species such as krill and small pelagics. CCAMLR has been a leader on how to deal with this ecosystem consideration. There are two approaches. The first was the traditional indicator for the target species (F and B), but takes into consideration that a larger biomass should be sustained than is the case under traditional fisheries management approaches. In essence the reference point for biomass of the target species changes, but the indicators stay the same. The second approach includes the monitoring of key predators of the targeted forage species under commercial exploitation. Indicators could include:

- Abundance of key predators of exploited stocks
- Condition of key predator
- Percentage of prey species in diet of predator

Maintenance of trophic level balance

This objective addresses emergent properties of ecosystems, and is somewhat controversial. There is a need to monitor properties of marine biological communities that are indicators of their structure and function, even though at this time there is no censensus on optional states of trophic level balance. Indicators include:

- Slope of the size spectrum
- Pauley's FIB index
- Aggregate removals by fishing at each trophic level

The data required for the above indicators are already been collected on the Scotian Shelf. The indicators, however, are not being routinely tracked over time.

Summary on additions to present monitoring activities

The Canadian LMR-GOOS workshop indicates that there is a need to augment the present monitoring program for the Scotian Shelf (and the rest of Atlantic Canada waters) if the broader ecosystem objectives are a component of integrated oceans management. The additions include:

- Bottom areas disturbed by ocean use activities
- Benthic community monitoring in disturbed and undisturbed areas by habitat type
- Targeted surveys for species-at-risk

- By-catch of species-at-risk and other mortalities due to human activities
- Numbers and locations of spawning populations for exploited species
- Selection differentials for certain exploited species
- Sex ratio of exploited species
- Condition, abundance and food habits of selected key predators on forage species

Research needs in support of Monitoring

A key challenge in the transition to integrated management of ocean uses is the need to assign causality to observed charges in marine ecosystems. If a change is observed in an indicator will we be able to associate that change with natural environmental variability or impacts of a particular ocean industry (e.g. oil/gas, aquaculture, fishing). Thus it is essential to monitor a broader suite of oceanographic and atmospheric indicators that allow description of natural climate variability and modeling of impacts. A second key area of research is on benthic habitat classification and definition of geographic spacing of MPAs. What percentage of the benthos for a given 'ecosystem type' should be undisturbed and what geographic pattern is required?

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2.4 YELLOW SEA AND EAST CHINA SEA

A. Introduction

Physical features

The Yellow Sea is a large inlet of the western Pacific lying between China and the Korean Peninsula (Figure 1). The area of the Yellow Sea proper (excluding the Bohai Gulf) is 404,000 km^2, and its mean depth is 44 meters. Along the west coast of Korea, a relatively high-salinity warm current (a branch of the Kuroshio Current) flows northward. Along the continental coasts southward-flowing currents prevail, which strengthen remarkably in the winter monsoon period when the water is cold and turbid with low salinity. In spring and summer, the upper layer is warm and diluted by the freshwater from rivers, while the deeper water remains cold and saline. The East China Sea, which has an area of 752,000 square kilometers, is largely shallow, with 71% of the area less than 200 meters and an average depth of only 350 meters (Figure 1). The shallow shelf areas are covered with sediments from the bordering land masses deposited mainly by the Yangtze and other rivers near the northern part of the sea.

Winds influence water circulation in the Kuroshio Current, a north-flowing branch of the warm North Equatorial Current that flows near Taiwan. Some of the Kuroshio enters the eastern part of the East China Sea then diverts eastward back out into the Pacific and flows east of Japan.

Strengthened by monsoon winds, it is at its fastest in summer, and the axis is displaced well into the East China Sea. This warmed surface water varies from 30° in the south to 25° in the north. In winter, northerly monsoon winds modify the circulation, and the north-flowing Kuroshio, though still important, is reduced in strength, while southerly flowing coastal currents are strengthened. This brings in colder water, with temperatures of 5 °C in the north 23 °C in the south.

Because of the constricting nature of the adjoining Yellow Sea and the funnel shape of some of the inlets on the mainland, tidal ranges are especially high along the coast of China. For example, the spring tide range, which is highest in summer and winter, is as much as 7 meters at Sansha Bay and 11 meters at Hangchow Bay.

Dominant biological resources and fisheries

The fauna of resource populations in the Yellow Sea and the East China Sea is composed of species with various ecotypes. In the Yellow Sea, fish are the main resource and about 200 fish species are found. Of these, 45 are warm water forms, 46 are warm temperate forms, and 9 cold temperature forms.

When water temperature begins to drop significantly in autumn, most resource populations migrate offshore toward deeper and warmer waters and concentrate mainly in the Yellow Sea depression. There are three overwintering areas: the mid-Yellow Sea, 34° to 37°N, with depths of 60 to 80 meters; the southern Yellow Sea, 32° to 34°N, with depths about 80 meters; and the northern East China Sea. The cold temperature species (e.g., eel-pout, cod, flatfish, and Pacific herring) are distributed throughout these areas, and many warm temperature species and warm water species (e.g., skates, gurnard, *Saurida elongata*, jewfish, small yellow croaker, spotted sardine, fleshy prawn, southern rough shrimp, and cephalopods) are also found there from January to March. In the southern Yellow Sea, all species are warm temperate and warm species (e.g., small yellow croaker, *Nibea alibiflora*, white croaker, jewfish, *Setipinna taty*, red seabream, butterfish, and chub mackerel). Their main overwintering period is from January to April. The deep water areas of the central Yellow Sea and northern East China Sea are the overwintering grounds for most species that migrate over long ranges.

The commercial utilization of fisheries resources in the Seas dates back several centuries. With the introduction of bottom trawl vessels in the early twentieth century, many stocks began to be intensively exploited by Chinese, Korean and Japanese fishermen, and some economically important species such as the red seabream declined in abundance in the 1920s and 1930s (Xio, 1960). The stocks remained fairly stable during World War II (Liu, 1979). However, due to a great increase in fishing effort and its expansion to the entire Yellow Sea, by the mid-1960s nearly all the major stocks were being heavily fished. Since then, the composition of the fish catch has changed greatly (Xia, 1978; Liu, 1979; Chikuni, 1985; Kang, 1987; Zhang and Kim, 1999).

The Yellow Sea is one of the most intensively exploited areas in the world. It is a multispecies, multinational fishery. The number of species commercially harvested is about 100 including cephalopods and crustacea. The abundance of most species is relatively small, and only about 20 species exceed 10,000 metric tons (mt) in annual catch. Table 1 shows major commercial species in the Yellow Sea and the East China Sea. These are the commercially important species and account for 40 to 60% of the annual catch. Demersal species are the major component of the resources and account for 65 to 90% of annual total catch. The resource populations of demersal species such as small yellow croaker, hairtail, large yellow croaker, flatfish, and cod declined in biomass by more than 40% when fishing effort increased threefold from the early 1960s to the early 1980s.

The total catch by these countries has increased from about 4.6 million metric tons (mmt) in 1980 to about 7.2 mmt in 1995 (Table 2). This increase is mostly due to increased catch by China. For Japan, total catch in the two seas has decreased continuously, while China's catch showed continuous increase in the two seas since 1980. Catch by Korea decreased in the Yellow Sea, but is stable in the East China Sea (Table 2).

Population fluctuations

Shifts in species dominance in the Yellow Sea are outstanding. The dominant species in the 1950s and early 1960s were small yellow croaker and hairtail, while Pacific herring and chub mackerel became dominant during the 1970s. Some smaller-bodied, fast-growing, short-lived, and low-value fish (e.g., *Setipinna taty*, anchovy, scaled sardine) increased markedly in abundance about 1980 and have taken a prominent position in the ecosystem resources thereafter. As a result, some larger-sized and higher trophic level species were replaced by smaller-bodied and lower trophic level species, and the resources in the Yellow Sea declined in quality. About 70% of the biomass in 1985 consisted of fish and invertebrates smaller than 20 cm, and the mean body length in the catches of all commercial species was only 12 cm while the mean body length in the 1950s and 1960s was over 20 cm. Thus it appears that the external stress of fishing has affected the self-regulatory mechanism of the Yellow Sea ecosystem (Tang, 1987a).

According to species compositions in catches by Korean coastal and offshore fisheries in the Yellow Sea and the East China Sea, there were substantial changes in the compositions in 1960-1997. In the 1960s small yellow croaker and hairtail were the two most important species, but filefish was the most important species from mid-1970s to 1980s. In 1990s filefish disappeared and anchovy became the most important species.

Environmental influences on living marine resources

The Yellow Sea and the East China Sea are located at mid latitudes, between the North Pacific and the Asian continent, and under the influence of the westerly wind and the monsoon, respectively. Hence the wind and river discharge fluctuate not only seasonally but also interannually and interdecadally due to the extratropical effect of ENSO events and climate shifts, which affect fish recruitment and ecosystem structure as well as the physical environment significantly (Sugimoto et al. in press).

Although overexploitation has been the main cause of shifts in resource population in the Yellow Sea ecosystem, natural conditions may have had an important effect on the long-term changes in dominant species. The catch of warm and temperate water species tends to increase during the warm years, while the catch of boreal species tends to increase during the cold years (Xia, 1978). The pattern of filefish catch reflects the climatic regime shifts which occurred in 1976 and in 1989/90 in Korean waters (Zhang et al., in press).

B. MONITORING REQUIREMENTS

1. Oceanographic and Atmospheric Information

The oceanographic and atmospheric information for the Yellow Sea and the East China Sea could be collected by observations at coastal stations, by regular *in situ* oceanographic cruises using research and fishing vessels, by drifters and by receiving remote-sensed satellite information for SST and ocean color. In 1997 the Northeast Asia Region GOOS (NEAR-GOOS) program established a data exchange system for the real time and delayed modes data base (Japan Meteorological Agency, 1999). The minimal initial monitoring requirements are listed as follows:

Atmospheric variables

Air temperature
Wind stress
Precipitation
Air pressure

Physical oceanographic variables

Sea temperature
Salinity
Currents
River discharge

Sea level and wave height

Chemical variables

Nutrients
Dissolved oxygen

Phytoplankton, primary production

Species composition
Distribution
Abundance/Biomass
Chlorophyll-a
Size spectrum

Zooplankton (including eggs and larvae)

Species composition
Distribution
Abundance/Biomass
Size composition
Secondary production (if possible)

Benthos (non-commercial species)

Species composition
Distribution
Abundance/Biomass
Size composition
Diet

2. Fisheries and fish biological information

The fisheries data for commercially important species required to construct a historic time-series should be collected. The minimum data needed for each fish species are as follows:

<u>Pelagic forage and commercial finfish</u>

Catch in weight or in number by area
Catch per unit of effort (CPUE) by area
By-catches and discards
Length measurements
Weight and sex of individuals
Otoliths or any other ageing characters
Gonad samples
Stomach samples
Eggs and larvae samples

Top predators (whales, dolphins, porpoises, seals, sharks, sea birds)

Abundance
Stomach samples
Breeding success

3. Monitoring scheme

Existing programs and methods

Currently, regular oceanographic surveys are satisfactorily conducted in the Yellow Sea and the East China Sea by Korea and Japan. The surveys include temperature, salinity, DO, and phytoplankton at the surface, 20 m, 50 m, and the bottom layer on a bimonthly basis. Also, surveys of nutrients and zooplankton have been conducted. Regular observation lines and stations are made by the National Fisheries Research and Development Institute around the Korean coast. In addition, regular observation stations measure air and seawater temperatures and meteorological parameters. Oceanographic observation lines and stations off the west coast of Japan are monitored monthly with research vessels by Japan Fisheries Agency and related prefectural fisheries institutes. The Japan Meteorological Agency also has seasonal oceanographic observation lines and a moored buoy station in the East China Sea. The observations made by research vessels cover not only hydrographic parameters but also nutrients, phytoplankton and zooplankton.

However, there are no regular fishery-independent surveys for finfish and shellfish species in this region. Some irregular surveys are conducted by each country for targeting some important commercial species such as three years' demersal fish surveys in the East China Sea by Korea, pelagic fish surveys by Japan, acoustic and bottom trawl surveys by China.

The total removals of fish and other organisms from this region are currently monitored by each country, although the quality of catch data is different by nation. Landings for commercial finfish and shellfish are recorded or reported to each governmental agency, however, discards and by-catches of non-commercial species are not always reported.

Required monitoring

Fishery-independent surveys of commercial finfish and blue crab should be conducted annually. Especially, during the spawning season for commercially important species, data on sea temperature, salinity, phytoplankton and zooplankton are desirable to be obtained monthly in order to study the mechanisms of the recruitment process in early life stages.

Continuous plankton monitoring by using CPR or ship-intake water samples across the Yellow Sea and the East China Sea is highly recommended, although the existing Yellow Sea Large Marine Ecosystem program has a plan to conduct CPR monitoring in the Yellow Sea (Inchon-Weihai and Inchon-Shanghai).

Data for estimating abundance of top predators such as birds, seals, dolphins and whales, sharks, tuna should be collected on a yearly basis.

Records of discards and by-catches should be collected, but as an initial step, detailed data of discards and by-catches could be obtained from some fishing vessels through observer programs or special surveys on board.

For other categories, the existing methods above could be maintained continuously. Higher-level stock assessments that combined with marine environmental factors would be possibly available by strengthening monitoring efforts mentioned above.

C. MODELING REQUIREMENTS

Population parameters

Growth modeling (including larval stage)
Mortality modeling (if possible, stage-based)

Selectivity and recruitment modeling
Reproduction modeling (maturity, fecundity)
Trophodynamics modeling

Abundance/Biomass

Age-structured analysis for major stocks
Egg production modeling
Egg and larval dispersion modeling (combined with recruitment)
Hydroacoustics modeling

Stock assessment

Production modeling
Yield- and spawning biomass-per-recruit analyses
Stock-Recruitment modeling that incorporates environmental variables

Ecosystem assessment

Ecosystem modeling (ECOPATH, ECOSIM, etc.)

D. PRODUCTS

The basic monitored data of atmospheric and oceanographic information are used to estimate the following items:

1) Detecting abnormal ocean condition, such as El Nino/La Nina, or climatic regime shifts
2) Upwelling activity/Frontal activity

3) Advection index/Eddies
4) Ocean circulation pattern
5) Stratification
6) Eutrophication
7) Primary and secondary production
8) Potential fish production
9) Biodiversity
10) Habitat changes
11) Ecosystem changes

The basic monitored data of fish and fisheries are used to estimate the following items.

1) Length and age structures
2) Standardized effective fishing effort
3) Length-weight relationship
4) Population parameters
5) Abundance or biomass
6) Unit stock identification
7) Standard stock assessments (SPM, YPR/SBPR, SRR)
8) Community structure
9) Predation mortality
10) Bycatch/incidental mortality
11) Inputs to multi-species models
12) Biodiversity
13) Indicators of ecosystem changes
14) Information for fisheries management

E. CAPACITY BUILDING REQUIREMENTS

Hydroacoustic technique training
Satellite remote sensing for SST, ocean color and currents
Statistical analysis including GIS technique
Species identification for eggs and larvae of fish and shellfish
Age determination technique
Stock assessment technique
Ecosystem modeling technique (ECOPATH, ECOSIM, etc.)

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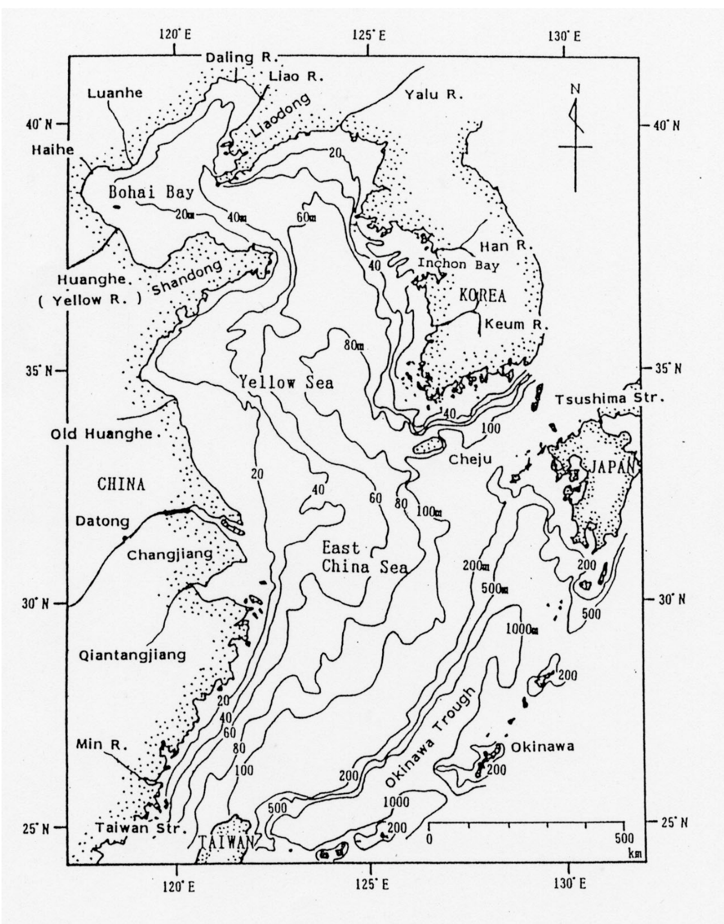
Table 1. Major commercial species in the Yellow Sea and the East China Sea (most important species shown in bold)

COMMON NAME	Species Name
DEMERSAL AND SEMI-DEMERSAL FISHES	
Small yellow croaker	***Pseudosciaena polyactis***
Hairtail	***Trichiurus lepturus***
Filefish	*Stephanolepis cirrhifer*
Pomfret	*Pampus argenteus*
Corvenias	*Collichthys niveatus*
Large yellow croaker	*Pseudosciaena crocea*
White croaker	*Argyrosomus argentatus*
Brown croaker	*Miichths miiuy*
Roundnose flounder	*Eopsetta grigorjewi*
Bastard halibut	*Paralichthys olivaceus*
Common seabass	*Epinephelus septemfasciatus*
Pacific cod	*Gadus macrocephalus*
Puffers	*Tetraodontidae*
Sharptoothed eel	*Muraenesox cinereus*
Red seabream	*Pagrus major*
Sea-devil	*Lophiomus setigerus*
Bigeyed herring	*Herklotsichthys zunasi*
Rockfish	*Sebastes inermis*
Flathead	*Platycephalus indicus*
Skateray	*Raja kenojei*
PELAGIC FISHES	
Anchovy	***Engraulis japonica***
Sardine	*Sardinops melanostictus*
Pacific herring	*Clupea pallasii*
Mackerel	*Scomber japonicus*
Horse mackerel	*Trachurus japonicus*
Spanish mackerel	*Scomberomorus niphonius*
SHELLFISHES	
Cuttlefish	***Sepia esculenta***
Blue crab	*Portunus trituberculatus*
Large shrimp	*Penaeus orientalis*
Common squid	*Todarodes pacificus*

Table 2. Catches by nation in the Yellow Sea and the East China Sea
(unit : ten thousand metric tons)

YEAR	YELLOW SEA				EAST CHINA SEA			
	Korea	China	Japan	Total	Korea	China	Japan	Total
1980	22.8	51.5	6.7	81.0	89.7	141.5	150.0	381.2
1985	25.3	61.9	6.2	93.4	100.9	169.0	141.7	411.6
1990	23.9	108.6	5.5	138.0	121.9	207.3	135.5	464.7
1995	17.8	163.1	2.9	183.8	102.3	359.6	76.3	538.2

Figure 1 – The Yellow Sea.



2.5 REGIONAL FISHERIES OBSERVING SYSTEM FOR THE GULF OF GUINEA

A. Introduction

The waters of the Gulf of Guinea are those of the Guinea Current Large Marine Ecosystem (LME) which extends from Bissagos Island in the north (Latitude 11° N, Longitude 16° W) to Cape Lopez in the south (Latitude 0° 41´S, Longitude 8° 45´E). The Guinea Current LME may be subdivided into three subsystems: the Sierra Leone - Guinea plateau subsystem stretching from Bissagos Island to Cape Palmas on the western part of Côte d'Ivoire; the Central West African (or western Gulf of Guinea) subsystem from Cape Palmas to Cotonou, Republic of Benin and the eastern Gulf of Guinea subsystem from Cotonou to Cape Lopez (Figure 1).

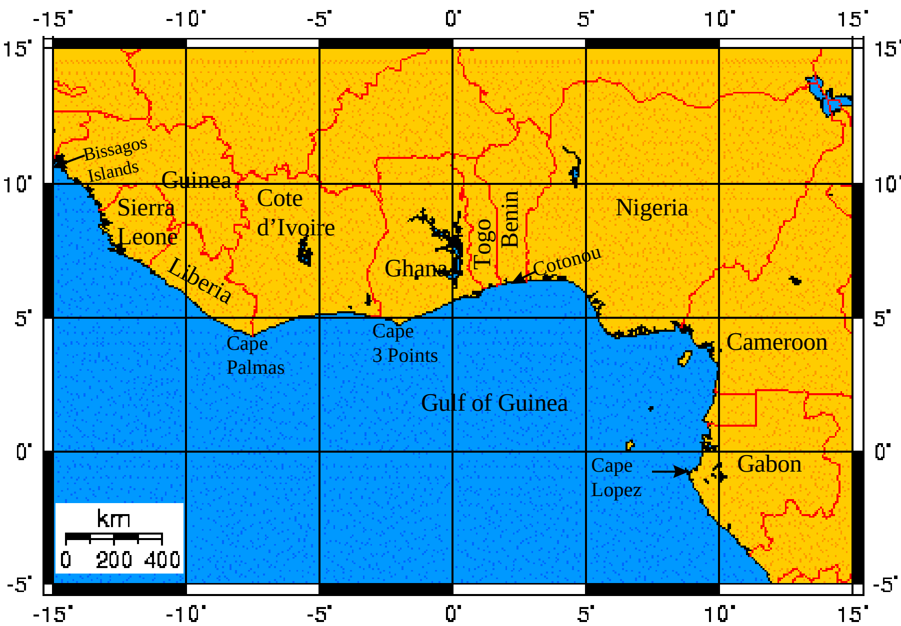


Figure 1: Map of the Gulf of Guinea showing some of the areas and landmarks mentioned in the text

The GOOS-LMR panel endorses a regional approach to ocean monitoring because the spatial scale is small enough for a homogeneous observing system to be effective. in this paper a regional fisheries observing system for the Gulf of Guinea is proposed as an example of a GOOS approach monitoring system for low latitude, developing nations. The same system might be applied in analogous tropical marine ecosystems worldwide, e.g., the Gulf of Thailand, Northeast South America, etc.

B. General Profile of the Gulf of Guinea

B.1 Physical characteristics of the Gulf of Guinea

In general the continental shelf of the area is narrow ranging between 15 and 90 km. The bottom deposits in the area are principally sand, mud and shell, in varying amounts and combination (Williams, 1968). The coastline is generally low lying and interspersed with marshes, lagoons and mangrove swamps. A number of estuaries interrupt the barrier beaches that separate mangrove swamps from the sea. The main supply of sediments to the Gulf of Guinea comes from rivers and coastal erosion. A number of major rivers, including the Niger and Benue (Nigeria), Volta (Ghana), and Comoe (Côte d'Ivoire), enter the Gulf of Guinea.

B.2 Hydrography

Except for the occurrence of a seasonal coastal upwelling in the Côte d'Ivoire - Ghana sector there is no great variation in the hydrographic conditions in the entire Gulf of Guinea. Except off Ghana, Côte d'Ivoire, the renewal of surface waters in the Gulf of Guinea is limited and dominated by river influence as opposed to upwelling and results in low productivity.

The coastal hydrography of the Côte d'Ivoire - Ghana sector is generally divided into four regimes: a short cold season in December – January (i.e. minor upwelling), a long warm season between February and June (thermocline period), a long cold season between June and October (i.e. major upwelling) and a short warm season in October – November. The upwelling that occurs in this part of the Gulf of Guinea differs from other eastern boundary systems where the upwelling is essentially of the Ekman-type. The mechanism causing the upwelling is not well understood although recent evidence shows that wind may play a more important role in it than previously thought.

These hydrographic regimes are the major factors which determine fish stock abundance and distribution in the Gulf of Guinea (Longhurst, 1969; Koranteng, et. al. 1996).

B.3 Fisheries of the Sub-region

The Gulf of Guinea is rich in living marine resources with the fishing industry providing livelihood for many fishers and foreign exchange for the countries. The fishery resources of the area are exploited by both artisanal and industrial fishing fleets, the latter being made up of both national and foreign flag vessels. Generally, over 60% of national fish landings in the sub-region are taken by artisanal fishers.

The fishery resources of the Gulf of Guinea may be classified as follows: (a) small pelagic species, (b) large pelagic species, (c) demersal species, and (d) molluscs and crustaceans. Some of the resources (mainly pelagic species) are shared by all the countries (e.g. Tunas) and others are shared by only some of the countries (e.g. *Sardinella aurita* in Côte d'Ivoire - Benin). Many fishes in the Gulf of Guinea ecosystem are dependent on estuaries and lagoons as spawning and nursery areas.

The small pelagics are the most abundant group of fish species in the sub-region. The important species are of the families Clupeidae (i.e. *Sardinella aurita*, *S. maderensis*, *Ethmalosa fimbriata*, and *Illisha africana*), Engraulidae (of which there is only one species, i.e. *Engraulis encrasicolus*) and Scombridae (mainly *Scomber japonicus*). These species normally occur in coastal waters and their abundance and distribution are controlled mainly by the seasonal coastal upwelling (FRU/ORSTOM, 1976; Cury and Roy, 1991) or nearshore processes like rainfall and river discharge (Binet, 1982).

The most abundant and economically important large pelagic fish species in the sub-region are tunas made up mainly of skipjack (*Katsuwonus pelamis*), yellow-fin (*Thunnus albacares*) and big-eye (*Thunnus obesus*). These species occur in the whole of the eastern Atlantic Ocean and are caught throughout the year by tuna bait boats and purse seiners.

Stock assessment surveys conducted in the Gulf of Guinea have indicated that the same fish assemblages are represented over similar bottom types and water depths throughout the Gulf of Guinea (Williams, 1968; Villegas and Garcia, 1983; Longhurst and Pauly 1987). The basic assemblages are the sciaenid (characteristic members include *Brachydeuterus auritus, Galeoides* spp., *Pseudotolithus* spp. and *Arius* spp.), lutjanid (*Lethrinus atlanticus*, *Lutjanus* spp, sparid (shallow and deep components) (*Dentex* spp., *Pagellus bellottii*, *Balistes carolinensis* and *Epinephelus* spp.), deep shelf and upper slope assemblages (*Peristedion cataphractum*, *Antigonia capros, Chlorophthalmus* spp., *Epigonus* spp. and *Triglidae*).

Results of these surveys show that significant changes in the demersal fishery resources are in terms of dominant species and size structure of the fishes. For example, from virtually nowhere in surveys conducted in 1963/64, *B. carolinensis* (= *capriscus*) came to dominate the continental shelf ecosystem of the Gulf of Guinea (especially off Ghana and Guinea) in the 1970s and 1980s.

Due to the untrawlable nature of the seabed in deep waters in the sub-region (Williams, 1968), the commercial fishery generally operates in water depths shallower than 75 m. Consequently, coastal demersal resources in the sub-region are either fully exploited or over-exploited (FAO, 1998). On the contrary, demersal stocks in offshore waters (i.e. 75 - 200 m) appear under-exploited in the sub-region.

C. Objectives of a Gulf of Guinea LMR Observing System

To provide operationally useful information on the state of living resources and their ecosystems including tracking changes in the biological and physical components of the ecosystems. The observing system is intended to serve the purpose of providing adequate description of the current state of the ecosystem and eventually forecasting of future states.

The upwelling that occurs in the region holds the key to the nature and condition of fishery resources, especially pelagic resources. Therefore, observing systems which would facilitate the forecasting and monitoring of upwelling conditions (i.e. onset, duration and intensity) will be beneficial to the management of the fishery resources. A regionally co-ordinated observing system will contribute greatly to the understanding of a phenomenon that occurs on such a large scale as the upwelling.

D. Characteristics of the Observing System

Tables 1 and 2 (in the main body of the report) provide a set of possible observations and products that might form the basis of the Gulf of Guinea LMR-GOOS observing system. The LMR panel's "three-system approach" is used. This approach concentrates observations in coastal areas and relies on remote sensing and ships-of-opportunity to sample the open ocean.

Also monitoring systems for the open ocean, the coastal ocean, and inshore differ in the frequency of observations in time and space and to some extent in the variables observed.

The panel also proposes that in all monitoring systems for LMR purposes, there is a need to obtain information on atmospheric forcing, ocean velocity field, and distributions of temperature and salinity at the surface and in the surface layer. Such information is also required for monitoring ocean climate and the health of the ocean. Thus, the parameters to be monitored and frequency of observation are as listed in Table 1. Following 2.1 - Coastal Fisheries in Upwelling Systems, the marine and atmospheric parameters to be monitored are as follows:

- Air and sea temperatures
- Salinity
- Wind stress
- Nutrients
- Currents
- Chlorophyll
- Phytoplankton and zooplankton (species composition, distribution, abundance and biomass)
- Primary and secondary production (if possible)
- River discharge
- Rainfall
- Essential habitat

Surveys (acoustic, swept area) to estimate the abundance and distribution of small pelagic species (sardine, anchovy and mackerel) and demersal species are envisaged. Frequency of surveys and measurements are listed in Table 1. The basic fishery data to obtain from the surveys are as follows:

- Length frequency distribution
- Length-weight relationship
- Age structure
- Recruitment variability
- Abundance or biomass estimation
- Unit stock identification
- Feeding behaviour and stomach contents
- Reproductive aspects (i.e. sex ratios, spawning area and period, gonad weight, maturity states, etc.)
- Fish schools behaviour (i.e. migration patterns)

From the commercial fishery, catch and fishing effort are to be monitored to facilitate the use of indirect stock assessments methods (e.g. VPA) in monitoring the state of fishery resources. Assessment of discards and by-catches of all fishing fleets is required; this may be done through observer programs.

MONITORING REQUIREMENTS

The three subsystems of the Gulf of Guinea Large Marine Ecosystem could form the basis of the monitoring and observation activities. Within each subsystem the general observational requirements for the target variables must consider adequate spatial and temporal scales in accordance with the known environmental variability.

The oceanographic information would be collected either at coastal stations and/or during regular oceanographic cruises using research or fishing vessels, and ships of opportunity (spatial information). Information on SST and ocean colour could also be obtained by remote sensing. It is necessary to establish the temporal and spatial distributional patterns of the physical and chemical variables, especially in the western Gulf of Guinea upwelling system, and to relate these with atmospheric forcing and biological observations of the ecosystem. It would be desirable to know the general circulation pattern from direct currentmeter measurements, ADCP measurements or from hydrodynamic models applied to specific regions.

Crude measurements of phytoplankton and zooplankton size distributions are useful indicators of community changes, but detailed more time-consuming identification of species is required to adequately characterize changes. Information on plankton could be obtained from regular cruises or fisheries surveys.

Monitoring Scheme

The essence of the monitoring scheme is to detect changes in abundance of dominant organisms, in the distribution of spawning habitat, and in ocean structures and processes that affect the biological changes.

- Satellite observations of boundary and frontal features on the shortest possible scale.
- Monitoring of selected transects in critical areas at monthly or bi-monthly time scales for oceanographic and biological parameters.
- Bottom trawl surveys of demersal stocks once or twice a year during upwelling and thermocline periods.
- Acoustic surveys of pelagic species once or twice a year with complementary environmental and biological information.
- Monitor species composition, length-frequency and landings of artisanal fisheries on appropriate temporal scale.

MODELING REQUIREMENTS

- Monthly Sequential Population Analysis
- Growth Modeling
- Larval Growth and Mortality
- Stock-Recruitment Modeling
- Trophodynamic Modeling
- Zooplankton stage-based population models

E. Products and Potential Users of the Observing System

Potential users of the observing system are:

- Government Departments (e.g. Fisheries Directorates for management of fisheries, monitoring, control and surveillance activities, Wildlife Department)
- Researchers
- Universities
- Fishing companies
- Tourist Board and tour operators
- Navies
- Ports and Harbours Authorities
- Shippers' councils

The LMR-GOOS monitoring system in the Gulf of Guinea would produce a number of products to benefit users. These might include those products listed in Table 2.

F. Capacity Building and Funding

Within the sub-region, the level of competence to conduct fisheries and marine environmental monitoring varies greatly. The level of competence and availability of material resources appear to depend on the importance of the fishery sector in the national economy.

In some of the countries, there are research institutions charged primarily with the study of oceanography and fisheries (e.g. Centre des Recherches Océanologiques in Côte d'Ivoire, the Marine Fisheries Research Division in Ghana and the Nigerian Institute for Oceanography and Marine Research). Where there are no such institutions, data collection and some aspects of fishery research are carried out by university departments (e.g. Benin) or Fisheries Departments (e.g. Togo). Generally, however, management (processing, archival and retrieval), dissemination and utilisation of fisheries and marine environmental data pose serious problems in the region. Also, inadequate communication links hinder the dissemination and sharing of information within and between countries of the region (Nauen et al., 1996). Presently, no extensive regional databases exist in the Gulf of Guinea. The lack of data management capacity, as well as the lack of capacity to collect some basic fisheries and oceanographic information, currently preclude the ability to produce ecosystem-level analyses and forecasts. Once these basic capacities have been improved in the region, the development of ecosystem research and modeling capacities should be a priority.

Strategies to address these issues and for funding of the observing system are considered under the GOOS capacity building program under formulation.

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ANNEX III

LMR ELEMENTS OF THE GOOS INITIAL OBSERVING SYSTEM (IOS)

1. California Cooperative Oceanic Fisheries Investigations (CalCOFI)

The California Cooperative Oceanic Fisheries Investigations (CalCOFI) is a collaboration of the Marine Life Research Group of the Scripps Institution of Oceanography; the Coastal Fisheries Resources Division of the Southwest Fisheries Science Center, NMFS/NOAA; and the Marine Division, California Department of Fish and Game, Resources Agency. The program has routinely sampled the physical, chemical, and biological properties of the California Current System during the last 50 years. Recent data are available on the Web site, http://www.mlrg.ucsd.edu/calcofi.html.

The sample pattern and suite of properties measured on the 'core' time-series cruises has changed several times over this period. Initially an extensive grid of stations from the tip of Baja California to beyond Cape Mendocino was covered monthly. From 1961 – 1965, sampling was quarterly, and between 1966 and 1985 it was at three-year intervals. Since 1985 the frequency of sampling has been quarterly and sampling has focused on the region between Point Conception and the U.S. border with Mexico. The sample grid covers 94,000 square miles with 66 stations spaced at 20 to 40 nautical mile intervals. Each station consists of a series of 3 net tows [oblique bongo, Manta (neuston) tow, vertical pairovet (fish egg) tow], a CTD-Rosette cast (continuous measurements of T, S, PAR, fluorescence, 0_2, transmittance) and 20-24 10-liter rosette bottles are tripped in the upper 500 m for chemical determinations (S, 0_2, chlorophyll, nutrients). Primary production is measured once per day at the station coincident with local apparent noon. In addition to the station work, continuous measurements are made with ADCP (currents and backscatter), underway sampling system (T, S, chl-fluorescence, PAR), and the CUFES fish egg sampling system.

The CalCOFI hydrographic data are processed rapidly and are distributed in printed data reports and via the web (where the entire 50-year data set is available and can be searched). CalCOFI plankton samples are sorted by NMFS for biomass and the abundance of fish eggs and larvae, and the data are curated there. The plankton samples for the entire 50-year time-series are stored at SIO as part of the planktonic invertebrates collection where they are accessed by many researchers.

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2. Ocean Station P and Line P

Ocean Station P (50^0 00'N, 145^0 00'W) was operated as an ocean weather station from 19 December, 1949 through 20 June, 1981. Initially, observations consisted of twice-daily bathythermograph casts, but in July 1956 hydrographic casts and plankton hauls were added, with sampling through alternate six-week periods. In April 1959, sampling was added on stations between the coast and Station P, on the track known as Line P, and the number of stations was increased to 12. The weathership program ended in the summer of 1981. Since then, observations at Station P and Line P are made 3 to 4 times a year by the staff of the Institute of Ocean Sciences.

CTD casts have been conducted at 26 stations on Line P since 1982. From 1992, hydrocasts are made at five of these stations, to measure dissolved oxygen, nitrate, phosphate, and silicate. Primary productivity, chlorophyll concentration, and zooplankton tows (vertical bongo) have also been taken. At Station P, primary productivity and POC have been measured and sediment traps used for approximately 20 years. Onboard analysis of nutrients has been done at Station P since 1987.

For further information:
Whitney, F.A. and H.J.Freeland. 1999. Variability in upper-ocean water properties in the NE Pacific Ocean. Deep-Sea Research II 46, 2351-2370. http://www.pac.dfo-mpo.gc.ca/sci/Pages/linep.htm.

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3. Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Ecosystem Monitoring Program

The Commission for the Conservation of Antarctic Marine Living Resources, CCAMLR, implemented its Ecosystem Monitoring Program (CEMP) from 1987. CEMP involves monitoring selected predator, prey, and environmental indicators of ecosystem performance in order to detect changes and to determine whether these changes are due to natural events or to resource harvesting activities. The core of the program is the acquisition, centralized storage and analysis of standardized monitoring data, along with empirical and modeling-based research. Since 1987, CEMP has collected data on six bird and seal species at 15 sites around the Antarctic. Up to 14 parameters of predator performance and 10 parameters of prey and environmental performance are collected at each site.

The program is described in the following publication:

Agnew, D.J. 1997. The CCAMLR Ecosystem Monitoring Program. *Antarctic Science* **9**, 235-242.

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4. Program for Ocean Ecosystems Observing and Fisheries Change (ECOFISH)

Living marine resources are of significant importance to the economies of maritime nations such as Chile and to the well-being of their inhabitants. Furthermore, national investment in coastal and oceanic fishing is often significant.

In Chile, a program has been developed to provide information to better manage critical marine resources. The Program for Ocean Ecosystems Observing and Fisheries Change (ECOFISH), implemented by the Fisheries Research Institute (FRI), has since 1990 provided a framework for gathering information on Chile's marine systems (monitoring), generating derived products to detect the ecosystem changes and their effects on the large fisheries (modeling), and providing the necessary training (capacity building) to study the coastal upwelling ecosystems off the coast of Chile.

Applied fishery research conducted by FRI has focused on analysis of regional and local fisheries, and involves monitoring selected fisheries (e.g., horse mackerel, hake, sardine, anchovy, patagonian grenadier) and environmental indicators of their habitats. FRI has collected data on: fisheries statistics (catch, effort) on a daily basis; length-frequency (daily); length-weight relationships; trophodynamics (weekly); fleet activity monitoring (daily); and ground fish monitoring (daily). FRI also analyzes SST and remotely-sensed meteorological information (daily), records wind, atmospheric pressure, temperature, and humidity at a local scale (hourly), and collects environmental information, e.g., oceanographic data (T, S, σ-t, DO and chl-*a* from CTD casts). FRI also collects phyto-, zoo- and ichthyoplankton samples on spawning and groundfish fishing areas using research and fishing vessels. This information is deposited in a central database. Standardized monitoring data are used for modeling-based research.

ECOFISH provides information that will allow:

- description of ecosystem changes time, particularly fluctuations in abundance and spatial distribution of fish resources;

- interpretation of observed changes in relation to factors such as natural environmental variability, anthropogenic climate changes, and fishing activities;
- forecast of future marine ecosystem states along the coast of Chile.

ECOFISH results have been used to improve the forecasting and predictive capabilities of principal regional fisheries, to provide precautionary criteria for environment conservation, to promote the sustainable use of the marine resources, and to improve long term planning in the industrial fishing sector.

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5. Japanese LMR Observing System

The Japanese Fisheries Agency has been conducting monthly egg and larval surveys of target fish species during the main spawning season, combined with hydrographic observations and phytoplankton and zooplankton sampling, in cooperation with prefectural fisheries experimental stations since 1978. In addition to these monthly surveys, intensive surveys are carried out by the National Fisheries Research Institutes during the main spawning season (February to April), on an annual basis. These egg and larval surveys combined with hydrographic observations and plankton sampling will contribute to the IOS of LMR-GOOS.

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6. Korean LMR Observing System

Since 1961, on a bimonthly basis, regular oceanographic surveys for water temperature, salinity, and DO have been made at each of 175 stations on 22 lines around the Korean coast. After 1994 an additional two lines (315 and 316) and 26 stations were sampled four times a year, and after 1993 an additional one line (500) and 17 stations were sampled one or two times a year. Since 1967 air and water temperatures and meteorological parameters have been measured at 40 fixed stations.

NOAA satellite data have been received since 1989, and SeaWiFS satellite images have been received since 1997.

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7. Alg@line

The following information was provided by Alg@line project coordinators.

The Finnish Institute of Marine research is carrying out operational monitoring of the Baltic Sea environment through a joint effort of research institutes and shipping companies through Alg@line. Alg@line is a forerunner in the field of monitoring research. Alg@line monitors the fluctuations in the Baltic Sea ecosystem in real-time using several approaches.

Alg@line combines studies onboard research vessels with high frequency automated sampling on several merchant ships, CPR transects, satellite imagery, buoy recordings and traditional sampling in coastal waters. Ecosystem models are under development.

Without the high frequency observations from ships-of-opportunity, rapid fluctuations in the Baltic Sea ecosystem could not be monitored. Alg@line is the only research project which utilises the ship-of-opportunity technique in the monitoring of the state of the environment on this scale. Alg@line has analysers and sample collectors on five ships.

Unattended recordings and water sampling, including CPR tows, on board ships of the Silja Line and Transfennica, are the basis of the system. Satellite imagery (NOAA/AVHRR) provides basin-wide information on the distribution of surface accumulations of blue-green algae and the temperature of surface waters. Aerial surveys by frontier guard pilots record visible blooms. Research vessels perform specific case studies. Buoys record fluctuations in environmental parameters of high temporal resolution at fixed positions. Analysis of water samples provides information on phyto- and zooplankton species composition and nutrient composition. Toxicity of blooms is also determined. The CPR collects zooplankton from ships-of-opportunity.

Alg@line provides on-line information. The information based on the unattended recordings on the ships is available in real time at web site “Alg@line Database”. The Alg@line

Database provides information in Finnish, Swedish, Estonian and English. The web address is http://meri.fimr.fi.

Ecosystem models will be used to predict short and long-term changes for various parameters.

The main products are:

- weekly/daily reports on the state of the marine environment
- annual assessments on the state of the marine environment
- plankton species reports
- long term and seasonal variation in plankton, nutrients, oxygen, etc
- taxonomic phytoplankton sheets
- phytoplankton image gallery.

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8. Sir Alistair Hardy Foundation for Ocean Science Continuous Plankton Recorder (CPR) Survey

The CPR Survey has been in operation since 1931, and has maintained one of the longest time series in existence in marine science (see section 5.7, this report). Surveys are conducted on regular transects using ships of opportunity in the North Sea, the North Atlantic and from 2000 the Pacific. In addition to quantitatively collecting zooplankton and providing indices of phytoplankton biomass through "greenness indices," modern CPRs are instrumented with sensors to collect data on salinity, temperature and chlorophyll (as fluorescence). Additional sensors could be developed to measure oxygen and nutrients. While historically CPRs are towed at a constant ~10 m depth, recent design advances have produced an undulating CPR which oscillates between the surface and up to 100 m depth during a tow, providing two-dimensional profiles of plankton and their environment. The CPR survey comprises a cost-effective method to provide information on changes in the physics, nutrient chemistry, and lower trophic levels of marine ecosystems, particularly in open-ocean areas where research vessel costs are prohibitive. The CPR survey has been adopted as a program of the GOOS-IOS.

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9. ICES International Bottom Trawl Survey (IBTS)

The ICES IBTS have been conducted quarterly in a coordinated way by various North Sea countries. The surveys produce data on a range of commercial fish species, including herring, sprat, mackerel, cod, haddock, whiting, saithe and Norwegian pout), along with concomitant physical and chemical oceanographic data (temperature, salinity, nutrients). The surveys have been conducted since 1970, providing the basis for long time series. Information from the surveys is used to provide abundance indices for ICES fish stock assessments, and support research through the provision of regional maps of bottom characteristics such as salinity and temperature. Data are managed through a readily accessible database maintained by ICES. Given the comprehensive nature of these surveys, the long time series, and the international cooperation involved, the panel concluded that the IBTS are consistent with the principles of LMR-GOOS, and has been included in the IOS.

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10. Northwest Atlantic Ecosystem Trawl Surveys (Cape Hatteras to Cape Chidley)

The United States and Canada have been conducting bottom trawl surveys using a similar survey design and sampling protocol for several decades. The USA survey started in 1963, whereas the surveys on the shelf seas off Canada were initiated at different times (the Southern Gulf of St. Lawrence and Scotian Shelf Survey started in 1970). The geographic coverage of the aggregate surveys is from Cape Hatteras (North Carolina) to Cape Chidley (northern tip of Labrador). These surveys document changes in the spatial distribution of both commercial and non-commercial ‘trawlable’ species at depths of 50 to greater than 200 meters. Some 400 species of fish and invertebrates are represented in the data set. CTD profiles are also routinely collected over the whole time period. The USA surveys include information on diets of certain species. In recent years the Canadian surveys have included measures of nutrients and dissolved oxygen. The geographic and temporal scope of the integrated data allow changes in distribution and abundance of individual species to be tracked over their entire geographic range in response to changes in oceanographic conditions and fishing pressure. These surveys provide a unique data set on fluctuations at higher trophic levels that are useful in addressing the broader conservation objectives of integrated oceans management, including evaluation of biodiversity changes. Given the comprehensive nature of these surveys, the long time series, and the international cooperation involved, the panel concluded that they are consistent with the principles of LMR-GOOS, and should be included in the IOS. For LMR-GOOS needs, particular attention is needed to update the integrated data set to allow routine analysis of large scale spatial changes in distribution and abundance. The data set is presently integrated for the 1970 to 1994 period.

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ANNEX IV

LMR-GOOS PILOT PROJECTS

1. CPR Surveys in the Northeast Pacific

The MONITOR Task Team of the PICES CCCC program recommended that large scale measurements of zooplankton species composition and abundance be initiated in the NE Pacific. The CPR represented the best choice of instrument, because it has a proven record in the Atlantic and its sampling characteristics, although with some problems, are well known. In March 2000 a two-year sampling program will begin that will occupy two transects, as suggested by the Task Team. The first, from Prince William Sound, Alaska to Long Beach, California will be run five times a year, with approximately monthly spacing from March to August, and the second, a great circle route from Vancouver Island, Canada to the Bering Sea will be run once per year. The first line will sample Prince William Sound, the offshore region feeding the downwelling zone on the shelf, close to the center of the Alaska Gyre (crossing Line P) and will intersect the CalCOFI grid off California. The second line will cross the first and also run parallel to Line P. In the short term this research will provide data on plankton variability along these lines and will be used to design a long-term zooplankton sampling program for the NE Pacific. This future program would reflect improvements in the technology available to estimate plankton abundance and will enable the monitoring of climate change variability. PICES would like to see the CPR program as a Pilot Project within GOOS and would hope to work with GOOS to develop a long-term strategy.

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2. The BENEFIT Program/Benguela Current Large Marine Ecosystem Program

The BENEFIT (Benguela Environment and Fisheries Interactions and Training) Program was initiated in 1998 after four years of planning. It is a cooperative initiative between Angola, Namibia and South Africa, supported by fisheries institutes in the three countries and with financial support from Norway, Germany, the African Development Bank, the FAO, Japan, France, Iceland and the World Bank with the following goals:

To develop the enhanced science capability required for optimal and sustainable utilisation of the Benguela System's living resources by:

- Improving knowledge and understanding of the dynamics of important commercial stocks, their environment, and linkages between environmental processes and stock dynamics.

- Building appropriate human and material capacity for marine science and technology in the countries bordering the Benguela ecosystem.

A science plan and implementation plan have been compiled and the first research and monitoring projects have been started. Target species are hake, sardines, anchovy, horse mackerel, sardinella and rock lobster and the principal environmental parameters are temperature, winds, oxygen, zooplankton and top predators such as birds and seals. Transboundary issues, principal fish habitats and frontal zones are the initial focus of research and monitoring activities.

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3. Biological Action Centers (BACs)

It is recognized that certain coastal regions, particularly those where different water masses are dynamically mixed, are far more productive than the open ocean. Even these highly productive coastal regions are not uniform. Some areas of smaller spatial scale stand out because of the higher abundance of most species at several trophic levels. This abundance demonstrates the relevant contribution of these small spots to the overall system productivity. Some of these areas sustain high levels of biological activity throughout the full year, while in others this activity is seasonal.

Along the eastern boundary region of the North Pacific, within 160 km or less of the coast, biological activity is high in some relatively small areas. These areas are fixed in space because of coastal geography, and thus can be characterized as Biological Action Centers, or BACs. The high abundance of marine organisms found here at multiple trophic levels appears to be mostly a consequence of the increased concentration of primary producers.

BACs may represent an opportunity to improve the efficiency of LMR-GOOS sampling, by concentrating observations in these small areas of high biological activity. It is proposed that a pilot study be initiated to investigate BACs and their role in marine ecosystems. Specifically, the pilot project would: (i) identify existing BACs; (ii) determine the extent to which observations in BACs can be extrapolated to surrounding areas; and (iii) investigate the extent to which BACs provide an indication of climate change.

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4. GLOBEC-Associated Pilot Projects

The intensive sampling being conducted within diverse GLOBEC initiatives provides opportunities for evaluating monitoring strategies for GOOS. The Georges Bank component of US GLOBEC and the Scotian Shelf component of Canada GLOBEC provide examples that illustrate the potential benefits. Both Canada and the United States have already established shelf seas oceans monitoring programs that contain most of the components identified in the LMR-GOOS template for shelf seas monitoring. The respective GLOBEC programs on Georges Bank and the Scotian Shelf involve intensive seasonal sampling of plankton abundance over several years, with particular emphasis on zooplankton population dynamics. The longer term monitoring strategies for both countries include the use of Continuous Plankton Recorder (CPR) transects, complemented by relatively sparse (in both space and time) net sampling from research vessel surveys. CPR has well described limitations with respect to resolution of vertical zooplankton structure, but provides excellent broad-scale descriptions of plankton distributions at a modest cost. The vertical net sampling included in the present monitoring programs should help evaluate further the efficacy of CPR as the key measure of trends in zooplankton abundance and community structure. The intensive GLOBEC sampling will allow evaluation of the degree to which the zooplankton monitoring strategy being proposed by LMR-GOOS picks up the inter-annual variability.

In addition GLOBEC aims to enhance understanding of the role of variability in circulation and mixing on marine ecosystem structure and function. To the degree that explanatory power is generated by GLOBEC, the pilot LMR-GOOS/GLOBEC initiatives will generate increased understanding of monitoring requirements necessary for both interpretation of ecosystem change, and possibly forecasting of impacts of climate variability on living marine resources. The LMR-GOOS monitoring strategy needs to be adaptive, and pilot projects with GLOBEC should contribute in this respect.

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ANNEX V

CONTRIBUTION OF GLOBEC TO DEVELOPMENTS OF LMR MONITORING

GLOBEC is active in developing, and exploiting, new sampling and observational systems to provide real-time reporting of high-rate data that can be incorporated in data assimilation models to provide regional and global scale information. Such research efforts on new technologies are very relevant to the future of LMR-GOOS. Relevant GLOBEC research on sampling methodology focuses on obtaining size resolution and improved identification (by species) of phytoplankton and zooplankton as well as organisms as higher trophic levels including fish, and determination of *in situ* rate processes, such as mortality, grazing, and predation rates. New instrumentation and methodologies are essential for the execution of GLOBEC objectives. Many of the new approaches, for example acoustics and optics, are highly advantageous because they will provide large volumes of data for many biological variables. However, interpretation and calibration of the data are quite complex; "ground-truthing" using traditional sampling will be important, especially in the early stages of application. Comparisons of new, with existing technologies, should obviously form a significant component of the development of new technologies. Similarly, appropriate sampling designs need to be developed for each region, and for each technology. Comparisons of designs among LMR regions should be conducted.

Global synthesis requires that the data collected regionally are as comparable as possible, through the use of agreed sampling techniques and measurement protocols. GLOBEC is addressing the issue of core sampling protocols and methods inter-comparison. This is a critical task for LMR-GOOS as well; establishment of long-term trends in marine ecosystems requires standard, intercomparable data. Thus, in addition to helping to identify crucial variables and locations for observation, GLOBEC research will also help to provide new sampling and observational methodologies of relevance to LMR-GOOS.

Modeling within GLOBEC will be directed at elucidating the mechanisms linking biological and physical components of marine ecosystems and understanding the responses of ecosystems, particularly targeted populations of higher trophic levels, to various types of physical forcing and biological interactions. This will require the development of a hierarchy of models that will be coupled to process and observational programs. Multiscale models that are capable of assimilating physical, biological and chemical data are needed. The development of such models poses novel scientific and methodological issues and as a result provides GLOBEC with an opportunity to advance the state-of-the-art in marine ecosystem modeling. The goal is to develop ecosystem models that can predict the evolution at time scales from few days to years. Such predictions will be possible if coupled physical-biological interaction models are developed, and data assimilation techniques for initialisation and updating with multivariate data are carried out.

As has already been mentioned, research development of ecosystem models within GLOBEC is viewed as critical to transforming the LMR-GOOS observations into products of value to users. GLOBEC modeling is directed at elucidating the mechanisms linking biological and physical components of marine ecosystems and understanding the responses of ecosystems, particularly targeted populations of higher trophic levels, to various types of physical forcing and biological interactions. This requires the development of a hierarchy of models that will be coupled with the observational programs. Multiscale models that are capable of assimilating physical, biological and chemical data are necessary. The development of such models poses novel scientific and methodological issues and as a result provides GLOBEC with an opportunity to advance the state-of-the-art in marine ecosystem modeling. The goal is to develop ecosystem models that can predict the evolution at time scales from few days to years. Such predictions will be possible if coupled physical-biological interaction models are developed and data assimilation techniques for initialisation and updating with multivariate data are carried out. The outcome of this research should benefit LMR-GOOS.

The research being carried out within a number of GLOBEC field programs provides valuable practical opportunities for evaluating and developing monitoring strategies for LMR-GOOS (see Annex IV.4 – GLOBEC-Associated Pilot Projects). For example, the intensive sampling during the US GLOBEC and Canada GLOBEC studies on George's Bank and the Scotian shelf will identify key variables and locations likely to provide warning signals of impending climate changes and ecosystem responses, thus providing a basis for an effective ongoing observation program. Both Canada and the United States have already established shelf monitoring programs that contain most of the components identified by LMR-GOOS for shelf sea monitoring. The respective field programs involve intensive broad-scale seasonal sampling of plankton abundance, employing advanced technologies, with particular focus on zooplankton population dynamics. The resultant data-sets, analysis, and associated coupled physical-biological models, will provide an excellent research resource for LMR-GOOS development. The longer term strategies of both countries include the use of Continuous Plankton Recorder (CPR) transects, complemented by relative sparse (both in time and space) net sampling from research vessel surveys. The CPR has well described limitations with respect to resolution of vertical zooplankton structure, but provides excellent broad-scale descriptions of plankton distributions as modest cost (see Annex III, Initial Observing System). The vertical net sampling included in the present monitoring programs should help to further evaluate the efficacy of the CPR as a key indicator of trends in zooplankton abundance and community structure. The intensive GLOBEC sampling will allow evaluation of the degree to which the zooplankton monitoring strategy being proposed by LMR-GOOS picks up the inter-annual variability.

ANNEX VI

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ANNEX VII

LIST OF ACRONYMS

ADCP	Acoustic Doppler Current Profilers
Argo	Array for Real Time Geostrophic Oceanography
AVHRR	Advanced Very High Resolution Radiometer
BAC	Climate Alert Bulletin
BATS	Bermuda Atlantic Time Series
BCLME	Benguela Current Large Marine Ecosystem
CalCOFI	California Cooperative Fisheries Investigation
CBD	Convention on Biological Diversity
CCAMLR	Commission for the Conservation of Antartic Marine Living Resources
CECAF	Fishery Committee for the Eastern Central Atlantic
CPR	Continuous Plankton Recorder
CPUE	Catch Per Unit of Effort
CTD	Conductivity-Temperature-Depth probe
CUFES	Continuous Underway Fish Egg Sampler
DO	Dissolved Oxygen
ECOFISH	Program For Ocean Ecosystem Observing (Chile)
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EMP	Ecosystem Monitoring Program
ENSO	El Niño –Southern Oscillation
EPCS	Electronic Particle Counting System
EPM	Environmental Program for the Mediterranean
FAO	Food and Agriculture Organisation of the United Nations
FRI	Fisheries Research Institute
GIS	Geographic Information System
GLOBEC	Global Ocean Ecosystems Dynamics
GOOS	Global Ocean Observing System
HELCOM	Helsinki Commission
HOTO	Health Of The Oceans (IOC)
HPLC	High Performance Liquid Chromatography
IBM	Individual Based Models
IBTS	International Bottom Trawl Survey
ICES	International Council for the Exploration of the Sea
IOC	Intergovernmental Oceanographic Commission (UNESCO)
IOS	Initial Observing System of GOOS
LME	Large Marine Ecosystems
MODIS	Moderate Resolution Imaging Spectroradiometer
NAO	North Atlantic Oscillation
NEAR-GOOS	North East Asian Region GOOS
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration (USA)
OPCs	Optical Plankton Counters
PAR	Photosynthetic Active Radiation
PDO	Pacific Decadal Oscillation

PICES	North Pacific Marine Science Organisation
POC	Physical Oceanography Committee
RAC	Regional Analysis Centers
ROV	Remotely Operated Vehicle
SCOR	Scientific Committee on Oceanic Research
SeaWIFs	Sea-viewing Wide Field of View Sensor
SIO	Service Institution of Oceanography
SLH	Sea Level Height
SOI	Southern Oscillation Index
SST	Sea Surface Temperature
TAO	Tropical Atmosphere Ocean (buoy array)
UNFA	United Nations Fisheries Agreement
VPA	Virtual Population Analysis
WMO	World Meteorological Organization
XBTs	Expandable Bathy-Thermographs
YPR	Yield-Per-Recruit